STRAIN GAGE DATA PROCESSING FOR ESTIMATING
STRESS DISTRIBUTIONS AROUND PIPE CROSS
SECTIONS

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4

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by

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ABSTRACT

This thesis presents a method for estimating the distribution of stress components around the outer circumference of a cross section of a pipe, from the readings of strain gage elements arbitrarily positioned and oriented around this circumference. A least-squares procedure is used to obtain best estimates of the coefficients of Fourier expansions describing such distributions. A digital computer program was developed for applying the method. Data for testing the method and program were generated by a computer program using the best available theory of stress analysis in pipes. Methods for adding random errors to the data were adapted and used for closer simulation of actual situations.

A second problem treated in this thesis is that of inferring the loading acting through the cross section of a straight pipe of concentric bore from known stresses at points on the external surface of the cross section which is presumed to be distant from stress concentrations. It is shown that this inference can be made from stresses at only three points of the cross section. A digital computer program was developed to do this.

TABLE OF CONTENTS

1. Introduction.

In a thesis presented to the Naval Postgraduate School in May, 1966, LT Joseph W. Koch, Jr., USN, did pioneer work on the problem of obtaining optimal inferences of stresses in submarine main sea water piping, from strain gage readings taken during dockside hydrostatic tests and during submerged operations. This work provided a sequential procedure for determining such stresses, but it also indicated the need for many related investigations.

Two of these are treated in the present thesis. The first is that of inferring, in an optimal way, the distributions of stresses around the outer circumference of a given cross section of pipe from observations of strain obtained from an arbitrary distribution of strain gage elements around that circumference. There are several reasons for being interested in this problem. One reason is that even though the gage elements may be arranged in special patterns intended to simplify determining stresses (for example three-gage rosette arrangements), failure of any of the elements might make it difficult to make effective use of valid information obtained from closely related gages. Another reason is the ability to infer stresses from arbitrarily arranged gages, which is a logical step in investigating the most effective and most economical arrangements of gage elements.

Briefly, this problem is solved herein by constructing Fourier series representing the desired stress components. Theoretical considerations are used to evaluate the coefficients of the series in an optimal way, minimizing the sum of the squares of the residuals. A digital computer program was developed to support the theory.

The second problem treated here is that of inferring the force and moment components applied through a cross section of pipe and the internal pressure acting inside the pipe. It is shown that these values may be inferred from a knowledge of the state of stress at only three abritrarily chosen points at the external circumference of the cross section, and a digital computer program for making the corresponding evaluations was developed.

The solution of this problem assumes that the stress distribution is that given by what may be regarded as the best available current theory for the state of stress in a section of uniform pipe having concentric bore and remote from stress concentrations and other disturbances in the stress pattern.

A digital computer program to generate numerical data from the best available theory was developed. This data was used to test and verify the theory and the computer programs. Suggestions of how to extend the present work are given in Section 4.

The author would like to express his sincere appreciation to Dr. John E. Brock, Professor of Mechanical Engineering, Naval Postgraduate School, for his continued patience, efforts and most capable guidance while acting as faculty advisor in this work.

2.   Least-Squares Estimation of Stress Distributions at the External

     Circumference of a Pipe by Means of Fourier Expansions, Using

     Strain Gage Data.

          The usual method of estimating the stress distribution at

the surface of a body is by taking readings of strain gages grouped in

rosettes, to determine local principal stresses. Unless the strain

rosettes have a redundance of gage elements, when one or more of them

fail, it is difficult to make effective use of the information provided

by the elements which do not fail.

          The work that follows presents a method to estimate the stress

distribution around an external circumference of a cross section of pipe,

along a sequence of strain gage elements, which may or may not be group-

ed in rosettes. If one or more gage elements fail, the information

from the others is still useful.

          It is assumed that strain gage elements are arbitrarily placed

(a)   (b)
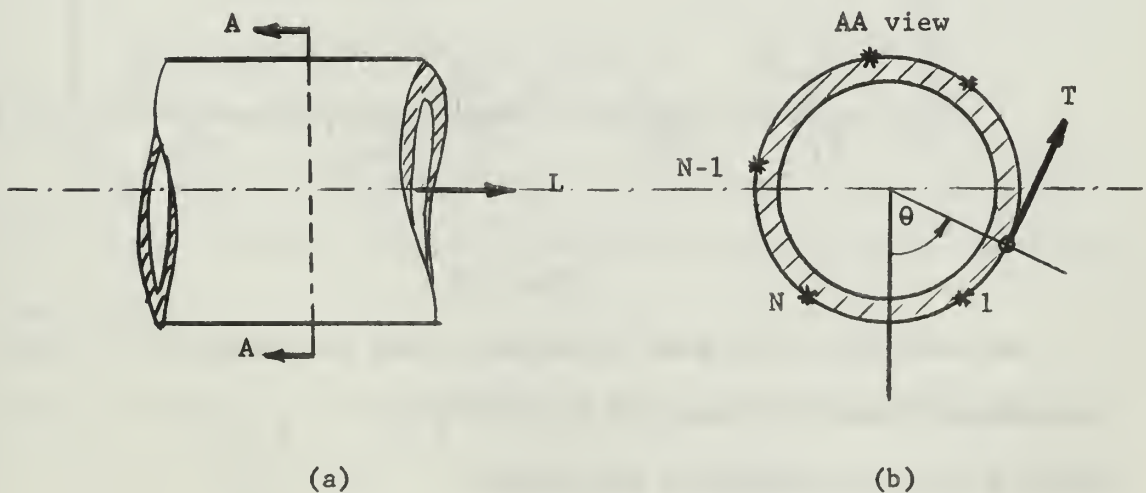
Fig. 2.1.

and arbitrarly oriented around the external circumference of a cross

section of pipe so as to measure the strain produced by application of

loading. Assume that there are N such elements as indicated in Fig. 2.1.

Define two orthogonal directions at the cross section, one normal to it, called longitudinal and represented by the letter L, and the other tangential to the external circumference, called tangential and represented by T; Fig. 2.1.b. Also define the angle θ as the angle between the vertical line that passes downward through the center of the cross section, and the radial line that passes through any specified point of the external circumference, measured as indicated in Fig. 2.1.b.

Measure the angular orientation of each gage element in the counterclockwise direction from the tangential axis T, and call this angle ∅.

A set of parameter-pairs can then be formed

$$(\theta_i \quad , \quad \emptyset_i) \qquad i = 1, 2, \ldots, N$$

which describe the position and orientation of each element, Fig. 2.2.
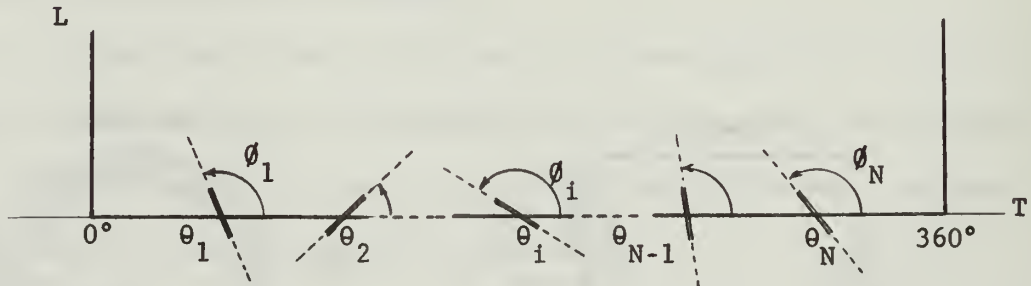
Fig. 2.2.

At each one of the gage locations, there are tangential, longitudinal, and shear strains, $(\epsilon_T)_i$, $(\epsilon_L)_i$, and $(\epsilon_{TL})_i$ respectively. The strains ϵ_y and ϵ_z along axis y and z, rotated the angle ∅ from the tangential direction Fig. 2.3., are related to the local
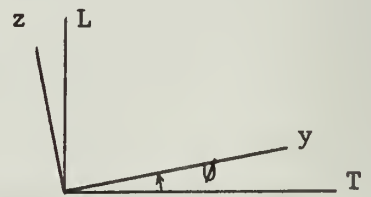
Fig. 2.3.

8

strains ϵ_T, ϵ_L and ϵ_{TL} by the strain tensor in the following way

$$
\begin{bmatrix} \epsilon_y & \frac{1}{2}\epsilon_{yz} \\ \frac{1}{2}\epsilon_{yz} & \epsilon_z \end{bmatrix} = \begin{bmatrix} \cos\emptyset & \sin\emptyset \\ -\sin\emptyset & \cos\emptyset \end{bmatrix} \begin{bmatrix} \epsilon_T & \frac{1}{2}\epsilon_{TL} \\ \frac{1}{2}\epsilon_{TL} & \epsilon_L \end{bmatrix} \begin{bmatrix} \cos\emptyset & -\sin\emptyset \\ \sin\emptyset & \cos\emptyset \end{bmatrix}
$$

The corresponding relations for the strains $(\epsilon_y)_i$ and $(\epsilon_z)_i$ along and transverse to the ith strain gage axis, are then

$$(\epsilon_y)_i = (\epsilon_T)_i \sin^2\emptyset_i + (\epsilon_L)_i \cos^2\emptyset_i + (\epsilon_{TL})_i \sin\emptyset_i \cos\emptyset_i \qquad (2.1.1)$$

$$(\epsilon_z)_i = (\epsilon_T)_i \cos^2\emptyset_i + (\epsilon_L)_i \sin^2\emptyset - (\epsilon_{TL})_i \sin\emptyset_i \cos\emptyset_i \qquad (2.1.2)$$

At the external surface, strains are related to the corresponding stresses as follows

$$\epsilon_T = (s_T - v\, s_L)/E \qquad (2.2.1)$$

$$\epsilon_L = (s_L - v\, s_T)/E \qquad (2.2.2)$$

$$\epsilon_{TL} = s_{TL}/G \qquad (2.2.3)$$

where   s is stress

v is Poisson's ratio

E is Young's modulus of elasticity

G is the shear modulus of elasticity

Substituting these expressions for the strains in the relations (2.1) for the strains along and transverse to the ith gage element and simplifying

$$(\epsilon_y)_i = (s_T)_i[1 - (v+1)\sin^2\emptyset_i]/E + (s_L)_i[1 - (v+1)\cos^2\emptyset_i]/E$$

$$+(s_{TL})_i \sin 2\emptyset_i/(2G) \qquad (2.3.1)$$

$$(\epsilon_z)_i = (s_T)[1 - (v + 1)\cos^2\phi_i]/E + (s_L)_i[1 - (v + 1)\sin^2\phi_i]/E$$

$$- (s_{TL})_i \sin2\,\phi_i/(2G) \qquad\qquad (2.3.2)$$

A strain gage element is sensitive not only to the strain along its own axis but also, to a small extent, to the strain at right angles to this axis. The transverse sensitivity is usually hard to obtain. It is rarely available from the manufacturer and may have to be inferred from an experiment. Nevertheless, it may be of importance and it is included in the theoretical development that follows.

For a particular gage element properly mounted on a given definite material, the relative change in electrical resistance, which is sensed by the strain indicator (or recorder), is given by a formula of the sort

$$\frac{\Delta R}{R} = F_y\,\epsilon_y + F_z\,\epsilon_z \qquad\qquad (2.4)$$

where R is the electrical resistance of the element, ϵ_y and ϵ_z are the strains along and perpendicular to its axis, and F_y and F_z are co-efficients which depend on the characteristics of the gage and the pro-perties of the material upon which it is mounted.

The ratio

$$k = F_z / F_y \qquad\qquad (2.5)$$

is called the transverse sensitivity (factor) of the gage, and the quantity

$$F' = (1 - k^2)\,F_y$$

is called the gage factor (which should be set on the sensor instrument). F' is the ratio of unit change in electric resistance to the quantity e, (indicated strain) sensed by the instrumentation.

Thus
$$e = (\frac{\Delta R}{R}) / F'$$

$$= (F_y \epsilon_y + F_z \epsilon_z)/[(1 - k^2)F_y]$$

$$= (\epsilon_y + k\epsilon_z)/(1 - k^2) \qquad (2.7)$$

This is what the instrumentation should indicate if there were no errors. Clearly for a gage with no transverse sensitivity, k = 0, and e = ϵ_y.

After substituting the expressions (2.3) for $(\epsilon_y)_i$ and $(\epsilon_z)_i$ in equation (2.7) and simplifying, the theoretical indicated strain e_i sensed along the ith strain gage element is given by

$$e_i = (s_T)_i[(1 - kv) - (1 - k)(1 + v)\sin^2\emptyset_i]/[E(1 - k^2)] +$$

$$+ (s_L)_i[(1 - kv) - (1 - k)(1 + v)\cos^2\emptyset_i]/[E(1 - k^2)2 +$$

$$+ (s_{TL})_i(1 - k)\sin 2\emptyset_i/[2G(1 - k^2)] \qquad (2.8)$$

Let the coefficients of the stresses in the above expression be represented by

$$A(\emptyset_i) = A_i = [(1 - kv) - (1 - k)(1 +v)\sin^2\emptyset_i]/[E(1 - k^2)] \qquad (2.9.1)$$

$$B(\emptyset_i) = B_i = [(1 - kv) - (1 - k)(1 + v)\cos^2\emptyset_i]/[E(1 - k^2)]$$
$$\qquad (2.9.2)$$

$$C(\emptyset_i) = C_i = (1 - k)\sin 2\emptyset_i/[2G(1 - k^2)] \qquad (2.9.3)$$

Then equation (2.8) can be put in the form

$$e_i = A_i(s_T)_i + B_i(s_L)_i + C_i(s_{TL})_i \qquad (2.10)$$

Any one of the stresses $(s_T)_i$, $(s_L)_i$ and (s_{TL}) has continuous and finite values around the external circumference of the pipe cross

11
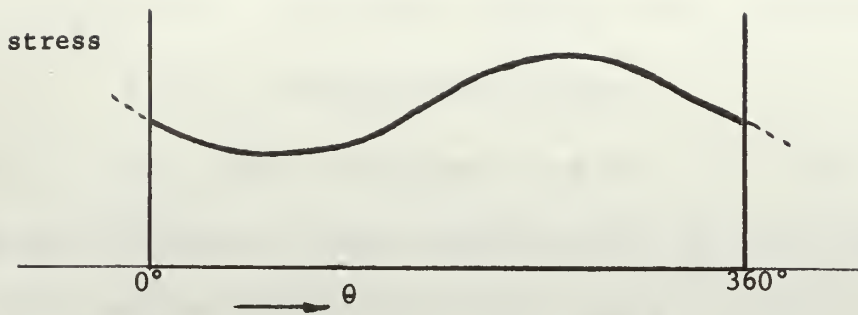
Fig. 2.4.

section, and can be represented as in Fig. 2.4.

The functional relation between stress and the angular position θ can be expanded in an infinite Fourier series[1]

$$(s_T)_i = \sum_{n=0}^{\infty} (s_{TA})_n \cos n\theta_i + \sum_{n=0}^{\infty} (s_{TB})_n \sin n\theta_i \qquad (2.11.1)$$

$$(s_L)_i = \sum_{n=0}^{\infty} (s_{LA})_n \cos n\theta_i + \sum_{n=0}^{\infty} (s_{LB})_n \sin n\theta_i \qquad (2.11.2)$$

$$(s_{TL})_i = \sum_{n=0}^{\infty} (s_{TLA})_n \cos n\theta_i + \sum_{n=0}^{\infty} (s_{TLB})_n \sin n\theta_i \qquad (2.11.3)$$

where

$(s_{TA})_n$, $(s_{TB})_n$, $(s_{LA})_n$, $(s_{LB})_n$, $(s_{SHA})_n$, and $(s_{SHB})_n$ are

as yet unknown numerical coefficients.

Sufficiently accurate values can be obtained if the expansion is carried to a finite number of terms, say P terms, in which case the index n would reach a maximum value of P/2. Call this value M. Then

$$(s_T)_i \approx \sum_{n=0}^{M} (s_{TA})_n \cos n\theta_i + \sum_{n=0}^{M} (s_{TB})_n \sin n\theta_i \qquad (2.12.1)$$

---

[1]The conventional expansion of a Fourier series is a constant term followed by a summation from 1 to ∞ . The same is obtained by eliminating the constant term and making summations from 0 to ∞ . This latter form will be used in this work to facilitate mathematical manipulations and later programming for a digital computer.

12

$$(s_L)_i \approx \sum_{n=0}^{M} (s_{LA})_n \cos n\theta_i + \sum_{n=0}^{M} (s_{LB})_n \sin \theta_i \qquad (2.12.2)$$

$$(s_{TL})_i \approx \sum_{n=0}^{M} (s_{TLA})_n \cos n\theta_i + \sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i \qquad (2.12.3)$$

Note that this expansion contains $6(M + 1)$ Fourier coefficients. If these expressions for the stresses are substituted into equation (2.10) for the strain e_i, theoretically sensed by the ith strain gage element,

$$e_i \approx A_i [\sum_{n=0}^{M} (s_{TA})_n \cos n\theta_i + \sum_{n=0}^{M} \ldots] +$$
$$+ B_i [\sum_{n=0}^{M} \ldots + \sum_{n=0}^{M} \ldots] + \qquad (2.13)$$
$$+ C_i [\sum_{n=0}^{M} \ldots + \sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i]$$

Call e_i^* the strain actually measured by the ith strain gage element, and E_i the difference between that measured strain and e_i, the strain that theoretically it should have measured, so that this error E_i is expressed as

$$E_i = e_i - e_i^* \qquad (2.14)$$

Let R be the sum of the squares of the errors, that is

$$R = \sum_{i=1}^{N} (E_i)^2$$
$$= \sum_{i=1}^{N} (e_i - e_i^*)^2$$
$$= \sum_{i=1}^{N} (e_i)^2 - 2 \sum_{i=1}^{N} e_i e_i^* + \sum_{i=1}^{N} (e_i^*)^2 \qquad (2.15)$$

To minimize R, partial derivatives respect to each of the $6(M + 1)$ Fourier coefficients are taken and set equal to zero:

$$\frac{\partial R}{\partial D_k} = 0$$

where $D_k = (s_{TA})_k$, $(s_{TB})_k$, $(s_{LA})_k$, $(s_{LB})_k$, $(s_{TLA})_k$, $(s_{TLB})_k$ in turn

for k = 0, 1, 2, ..., M

Taking derivatives of R from expression (2.15)

$$\frac{\partial R}{\partial D_k} = 0 = 2 \sum_{i=1}^{N} e_i \frac{\partial e_i}{\partial D_k} - 2 \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial D_k} \qquad (2.16)$$

Simplifying this

$$\sum_{i=1}^{N} e_i \frac{\partial e_i}{\partial D_k} = \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial E_k} \qquad (2.17)$$

Taking derivatives of e_i from expression (2.13)

$$\frac{\partial e_i}{\partial (s_{TA})_k} = A_i \cos k\theta_i \quad \text{for } k = 0, 1, 2, \ldots, M \qquad (2.18.1)$$

$$\frac{\partial e_i}{\partial (s_{TB})_k} = A_i \sin k\theta_i \qquad (2.18.2)$$

$$\frac{\partial e_i}{\partial (s_{LA})_k} = B_i \cos k\theta_i \qquad (2.18.3)$$

$$\frac{\partial e_i}{\partial (s_{LB})_k} = B_i \sin k\theta_i \qquad (2.18.4)$$

$$\frac{\partial e_i}{\partial (s_{TLA})_k} = C_i \cos k\theta_i \qquad (2.18.5)$$

$$\frac{\partial e_i}{\partial (s_{TLB})_k} = C_i \sin k\theta_i \qquad (2.18.6)$$

Note that there are $6(M + 1)$ derivatives of this form. Substituting in equation (2.17) the expression for e_i from equation (2.13)

$$\sum_{i=1}^{N} \left\{ A_i \left[\sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i + \ldots \right] + \ldots + C_i \left[\ldots \right. \right.$$

$$\left. \left. \ldots + \sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i \right] \right\} \frac{\partial e_i}{\partial D_k} = \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial D_k}$$

$$(2.19)$$

14

which is the same as

$$\sum_{n=0}^{M} (s_{TA})_n \left[\sum_{i=1}^{N} A_i \cos n\theta_i \frac{\partial e_i}{\partial D_K} \right] + \sum_{n=0}^{M} (s_{TB})_n \left[\sum_{i=1}^{N} A_i \sin n\theta_i \frac{\partial e_i}{\partial D_K} \right] +$$

$$+ \cdots + \sum_{n=0}^{M} (s_{TLB})_n \left[\sum_{i=1}^{N} C_i \sin n\theta_i \frac{\partial e_i}{\partial D_K} \right] = \sum_{i=1}^{N} e_i^{*} \frac{\partial e_i}{\partial D_K} \qquad (2.20)$$

for k = 0, 1, 2, ... , M

When the index n in the Fourier expansions is equal to zero, the terms containing $\sin(n\theta_i)$ are zero. This makes the coefficients $(s_{TB})_0$, $(s_{LB})_0$ and $(s_{TLB})_0$ also zero, reducing the Fourier coefficients to (6M + 3) and the same number of derivatives of the form $\frac{\partial e_i}{\partial D_k}$. There will be (6M + 3) equations in each of which appear all the Fourier coefficients. This makes a set of (6M + 3) equations with the same number of unknowns, (the Fourier coefficients), which can be solved.

Once the Fourier coefficients are solved for, they can be substituted in expressions (2.7) for the stresses. The stress distributions s_T, s_L and s_{TL} are defined then as functions of the angle θ over the complete external circumference of the cross section.

A digital computer program was developed to apply the theory of the preceding text. It was tested using a mathematical model of a cantilevered pipe. The program is called TERESITA and is presented in Appendix B of this thesis.

It was assumed that strain gages having a zero transverse sensitivity factor were placed at the external circumference of cross section No. 1, see Fig. A.1. in Appendix A. Four arrangements of gage elements

and several numbers of Fourier coefficients were used.

The first arrangement consisted of twelve strain gage rosettes equally spaced 30° from each other around the cross section. Each rosette has three gage elements oriented at 0°, 45° and 90° from the positive tangential axis. Runs were made with 11, 9, 7, 5 and 3 Fourier coefficients for each stress component.

The second arrangement consisted of twelve rosettes spaced as above but with elements oriented at 0°, 60°, and 120°. Runs were made for the same number of Fourier coefficients.

The third arrangement consisted of eight strain rosettes equally spaced 45° from each other. The rosettes had four gage elements oriented at 0°, 45°, 90° and 135° from the positive tangential axis. Runs were made for the same number of Fourier coefficients.

As input data for testing the program, stress distributions produced by the loading were evaluated at the external circumference of cross section No. 1. From the stresses, the theoretical strain that the gage element would sense, was computed. The stress distributions recovered by the program agreed in all cases with the input information. Results using eleven Fourier coefficients (for each stress component s_T, s_L and s_{TL}) are almost identical with those using only three coefficients.

Additional runs were made using the second arrangement of gages, but eliminating arbitrarily the readings of some of them. This is what would have to be done in an actual case if some gage elements were known to have failed. Results are satisfactorily close to the preceding ones. Other runs were made using a strain gage transverse sensitivity factor of 1%. The program recovered likewise the input information.

The fourth gage arrangement had one gage element every 10° around

the circumference with different orientation for each gage. Runs were made using the same number of coefficients.

All the runs described above were repeated introducing in the gage element readings small random errors so to simulate actual situations. Calculated loadings differed from the input loadings to a degree which depended in each case on the amount of error introduced.

The program and some sample numerical results of the runs made are presented in Appendix B of this thesis.

A more detailed discussion of the effects of changing the number of Fourier coefficients and gage element arrangement is presented in Appendix E.

3. Inference of the Loading Acting at a Cross Section of a Pipe of Concentric Bore from Stresses at the External Circumference of that Cross Section.

If stresses are known at a sufficient number of points around the external circumference of the cross section of a pipe of concentric bore at a distance from stress risers and concentrated loads, the loading acting at the cross section can be determined from theory.

It is intended to analyse the effects that such loads produce at a general point P under the conditions specified above. From this analysis, general conclusions will be reached which lead to a mathematical procedure to determine the loads.

Consider a cross section of pipe as specified above, Fig. 3.1. Choose reference axes x, y and z with the center point 0 as origin. Let

(a)   (b)
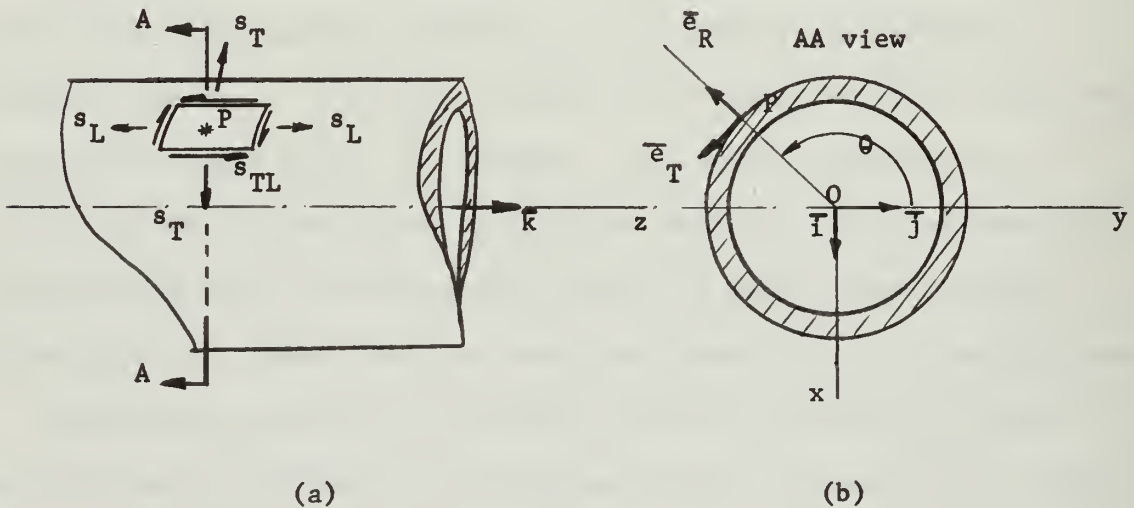
Fig. 3.1.

$\bar{i}$, $\bar{j}$ and $\bar{k}$ be unit vectors along the positive x, y and z axis so to form a right handed triad. Let $\bar{e}_R$ be a unit vector along the outwards direction of the radius that passes through the point P, and $\bar{e}_T$ another unit vector so that $\bar{e}_R$, $\bar{e}_T$ and $\bar{k}$ form a right handed triad. The angle θ is

measured from $\bar{i}$ counterclockwise to $\bar{e}_R$. Consider the differential area surrounding the point P. Assume that tensile stresses s_T and s_L (along the directions of $\tilde{e}_T$ and $\bar{k}$ respectively) and shear stress s_{TL}, are produced by internal pressure p and by a general force $\bar{F}$ and a general moment $\bar{\bar{M}}$ acting on the cross section at the center point 0.

Let the components of $\bar{\bar{F}}$ and $\bar{\bar{M}}$ in the $\tilde{e}_R$, $\bar{e}_T$ and $\hat{k}$ triad be (F_R, F_T, F_z) and (M_R, M_T, M_z) respectively, and in the $\bar{i}$, $\bar{j}$, $\bar{k}$ triad, (F_x, F_y, F_z) and (M_x, M_y, M_z).

From strength of materials considerations reviewed in reference 5, the stresses produced by p, $\bar{F}$ and $\bar{M}$ at the external point P are:

$$s_T = 2 p a^2 / (b^2 - a^2) \tag{3.1}$$

$$s_L = -M_T b / I + F_z / A \tag{3.2}$$

$$s_{TL} = M_z b / (2 I) + D F_T \tag{3.3}$$

where
- a = internal radius of the cross section
- b = external radius of the cross section
- A = cross sectional area
- I = moment of inertia of the cross sectional area about a diameter
- $D = [2 n a^2 + (2n - 2)b^2] / [4I(1 + v)]$
- v = Poisson's ratio
- n = v + 3/2

Making use of the two dimensional coordinate transformation tensor

$$\begin{bmatrix} M_R \\ M_T \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} M_x \\ M_y \end{bmatrix}$$

M_T can be expressed as

$$M_T = - M_x \sin \theta + M_y \cos \theta \tag{3.4}$$

Similarly,

$$F_T = -F_x \sin\theta + F_y \cos\theta \qquad (3.5)$$

The expression (3.2) for s_L can be transformed to

$$s_L = (1/A)F_z + (b/I)\sin\theta\, M_x - (b/I)\cos\theta\, M_y \qquad (3.6)$$

Multiplying through by (I/b)

$$(I/b)s_L = (I/(Ab))F_z + (\sin\theta)M_x - (\cos\theta)M_y \qquad (3.7)$$

Letting $(I/b) = g$, and $(I/(Ab)) = h$, both of which are cross sectional constants, substituting above and changing sides

$$h\,F_z + \sin\theta\, M_x - \cos\theta\, M_y = g\,s_L \qquad (3.8)$$

The preceding theory is applicable to a point on the exterior surface of a piece of straight, uniform, concentric pipe at a sufficiently great distance from its ends or other connections which might introduce local disturbances into the stress distribution. Presuming that these conditions are satisfied, we next turn to the matter of trying to infer the loading conditions at the cross section, i.e., F_x, F_y, F_z, M_x, M_y, M_z and p, from a knowledge of the stresses at several points on the external surface of the cross section.

For a general point P, s_L and θ are known and the only unknowns in equation (3.8) are F_z, M_x and M_y. Taking three such points at the cross section, the three unknowns can be determined proceeding as follows.

Assume that the angular positions for the points are θ_1, θ_2 and θ_3 and the axial stresses are s_1, s_2 and s_3 respectively. A set of equations can then be formed

$$h\,F_z + s\theta_1\, M_x - c\theta_1\, M_y = gs_1 \qquad (3.9.1)$$

$$h\,F_z + s\theta_2\, M_x - c\theta_2\, M_y = gs_2 \qquad (3.9.2)$$

20

$$h\, F_z + s\theta_3\, M_x - c\theta_3\, M_y = gs_3 \qquad (3.9.3)$$

where the letters s and c with no subscripts are abreviations for sin
and cos respectively. These abbreviations will be used throughout this
section.

The set of equations (3.9) is solved applying Cramer's rule

$$\text{Denominator} = \begin{vmatrix} h & s\theta_1 & -c\theta_1 \\ h & s\theta_2 & -c\theta_2 \\ h & s\theta_3 & -c\theta_3 \end{vmatrix}$$

$$= -h(\; s(\theta_1 - \theta_2) + s(\theta_2 - \theta_3) + s(\theta_3 - \theta_1)) \quad (3.10)$$

$$\text{Numerator of } F_z = \begin{vmatrix} gs_1 & s\theta_1 & -c\theta_1 \\ gs_2 & s\theta_2 & -c\theta_2 \\ gs_3 & s\theta_3 & -c\theta_3 \end{vmatrix}$$

$$= -g(\; s_1 s(\theta_2 - \theta_3) + s_2 s(\theta_3 - \theta_1) + s_3 s(\theta_1 - \theta_2))$$

$$(3.11)$$

$$\text{Numerator of } M_x = \begin{vmatrix} h & gs_1 & -c\theta_1 \\ h & gs_2 & -c\theta_2 \\ h & gs_3 & -c\theta_3 \end{vmatrix}$$

$$= -hg(\; c\theta_1(s_3 - s_2) + c\theta_2(s_1 - s_3) + c\theta_3(s_2 - s_1))$$

$$(3.12)$$

$$\text{Numerator of } M_y = \begin{vmatrix} h & s\theta_1 & gs_1 \\ h & s\theta_2 & gs_2 \\ h & s\theta_3 & gs_3 \end{vmatrix}$$

$$= -hg\; (s\theta_1(s_3 - s_2) + s\theta_2(s_1 - s_3) + s\theta_3(s_2 - s_1))$$

$$(3.13)$$

21

The values of F_z, M_x and M_y are found by dividing the respective numerator by the denominator.

The remaining components of the vectors $\bar{F}$ and $\bar{M}$ appear in the expression (3.3) for s_{TL}, which by using equation (3.5) can be transformed to

$$s_{TL} = (b/2I)M_z - D\sin\theta\,F_x + D\cos\theta\,F_y \qquad (3.14)$$

Multiplying through by $(1/D)$, letting $(-1/D) = g*$, $(-b/2ID) = h*$, both cross sectional constants, substituting in (3.14) and changing sides

$$h*\,M_z + \sin\theta\,F_x - \cos\theta\,F_y = g*s_{TL} \qquad (3.15)$$

This expression is of the same form as (3.8) which led to the evaluation of F_z, M_x and M_y by using information from three points. In this case the unknowns are M_z, F_x and F_y which can be evaluated by using the same three points and applying the same method. In this form the loads $\bar{F}$ and $\bar{M}$ are completely determined.

Since s_T is produced by the internal pressure p alone, it can be solved for from equation (3.1) with the information from any one of the three points used to evaluate $\bar{F}$ and $\bar{M}$

$$p = s_T(b^2 - a^2)/(2a^2) \qquad (3.16)$$

From the above development, it can be concluded that theoretically the loads $\bar{F}$, $\bar{M}$ and p acting at the cross section can be determined from known stresses at three points of the external surface of the cross section.

A digital computer program called TIBISAY was developed to apply the preceding treatment. The program was tested using a mathematical model of a cantilevered pipe as in Section 2 of this thesis. Stresses generated at cross section No. 1, at points 0°, 120° and 240° from the

vertical downwards direction were used. The recovered loads were almost
identical with the input ones producing the stresses. Deviations are
due to small round-off errors introduced by the computer. The program
and results of the test are presented in Appendix C of this thesis.

4.   Conclusions.

The results obtained in the tests for applicability of the theories developed in this thesis indicate that the proposed methods can be used for analysing stresses in pipes.

There are, however, many factors influencing the validity of the results. Some of them are related to the amount of error introduced when determining geometries and material properties. Others are due to proximity to concentrated loads and stress concentrations. Other factors are directly related to the degree of redundance of strain gage data, the number of gages used and their arrangement around the cross section, and the number of Fourier coefficients to be used. Also, it may be that the least-squares method used does not produce the best results; perhaps, by minimizing some other function of error, better results could be obtained.

First steps were taken to investigate further some of these factors. Appendix E of this thesis presents results of a survey made concerning the influence of the number of Fourier coefficients used in the accuracy of results. There are also preliminary results of the influence of the number of gage elements and their arrangement around the cross section. Due to time limitations, further investigations were not conducted.

The digital computer programs included in this thesis can be used to investigate deeper into the field. Some refinements of the methods can be added. It is believed that the following points should not be neglected.:

a.   Other criteria for minimizing errors can be investigated. A discussion of such criteria is given in reference 7 of this thesis. It is likely that some of the methods described there may have application in the pipe stress problem considered herein.

b. One may investigate the question of the minimum number of strain gage elements necessary to obtain acceptable stress distributions, and their orientation around the cross section. Similarly, the optimum number of elements and preferred orientation could be investigated.

c. While observing the results for a determined gage arrangement, it was noticed that good results were obtained using from 3 to 7 Fourier coefficients, but more than that produced bad results; using again 5 coefficients and changing the gage arrangement, good results were obtained for some arrangements and bad results for others. Some of these results are presented in Appendix G of this thesis. Further study could be made of the optimal number of Fourier coefficients to be employed.

d. A method for data rejection should be incorporated in the theory and computer programs. There are instances when it is obvious that a strain gage element has failed and the reading of that gage should be neglected. Usually bad gages are not easily identified and bad data is processed along with good data. There is the possibility of incorporating a data rejection procedure in the method developed in Section 2 of this thesis. One suggestion for such a procedure is given in the following.

The estimated Fourier coefficients of the stress distributions are evaluated from a minimization of the sum of the squares of the errors, i.e., the differences between the gage element readings and what they should have read theoretically. We can assume that these errors are random having a statistical normal distribution with mean and standard deviation which could be computed. Establishing a level of significance for a deviation to be sufficiently apart from the mean, one can reject the data having greater deviations and recompute the stress distributions with the remaining data. Similar screenings can be done with the

newly computed stress distributions until the remaining data have deviations under the level of rejection. This theory could be readily used if the redundance of data were large. Usually this is not the case and one must avoid rejecting data which are not perfect but which are useful and necessary. If the data is known to have a normal curve with a very sharp peak, bad data is easily determined and low significance levels can be used. If the bell is fairly flat, the majority of the deviations have pronounced deviations from the mean and the level of rejection becomes difficult to establish. The writer is inclined to think that there are criteria that may satisfy all conditions. Once they are found, the theory could be applied to this problem and to similar ones.

5.   Bibliography.

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APPENDIX A

DATA GENERATION THEORY AND RELATED DIGITAL COMPUTER PROGRAMS

The data used to test the applicability of the theories developed
in this thesis was generated for a mathematical model of a cantilevered
pipe of concentric bore subjected to internal pressure p and general
force $\bar{F}$ and general moment $\bar{M}$ applied to the tip. Details of this pipe
are shown in Fig. A.1. The following material properties, pipe dimensions,
and loads were specified:

(a)   (b)
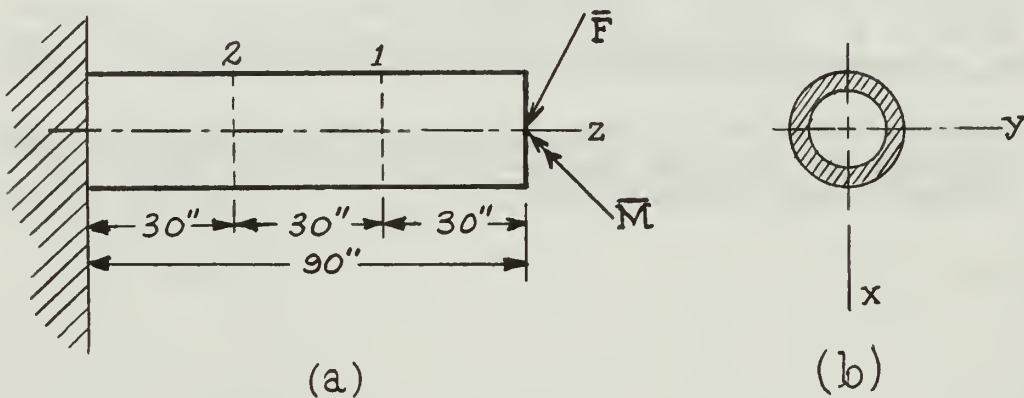
Fig. A.1.

E = 30,000 ksi

v = 0.3

Specific weight = 0.283 lb/in^3

External diameter = 12.0 in

Internal diameter = 10.0 in

$F_x = F_y = F_z$ = 100.0 lb

$M_x = M_y = M_z$ = 100.0 lb-in

p = 100.0 psi

Subroutine CANTIL presented herein in this Appendix, was used
to evaluate the tangential, longitudinal and shear stress distributions

at the external circumference of cross sections 1 and 2 of this pipe.

The stress distributions were used in turn to supply the data required

for the tests specified in other parts of this thesis.

This subroutine is used by either of the (main) programs TERESITA

or TIBISAY described in Appendices B and C. The arrangement of the card

input is indicated in Fig. B.1. of this thesis. Description and specifi-

cations for CANTIL follow this page.

DESCRIPTION OF SUBROUTINE CANTIL

Subroutine CANTIL evaluates the state of stress at any point of a cantilevered straight pipe of concentric bore, with internal pressure and loaded at the tip by general forces and general moments. The program is capable of analysing from 1 to 360 points in each of 1 to 5 cross sections of the pipe. The points have to be at the same radial distance from the center of the pipe, and separated from one another by angular intervals which are submultiples of 360°, from 1° to 360°.

The data deck, see Fig. B.1, includes the following cards:

Card No. 1. Format 3F20.8

    a.   External diameter of the pipe, inches.

    b.   Internal diameter of the pipe, inches.

    c.   Pipe length, inches.

Card No. 2. Format 3E20.8, 2F10.8

    a.   Young's modulus of elasticity, psi.

    b.   Shear modulus of elasticity, psi. This can be omitted in which case it will be computed by the program from $E/2(1 + v)$.

    c.   Coefficient of thermal expansion. This can be omitted. It is not actually used in any present application.

    d.   Poisson's ratio.

    e.   Specific weight of the material, pounds per cubic inch.

Card No. 3. Format 2I5, 5F10.5

    a.   Number of points to be analysed in each cross section.

    b.   Number of cross sections to be analysed in the pipe.

    c.   The distances from the tip of the pipe to the cross sections to be analysed, inches.

Card No. 4. Format F80.2

    a. Radial distance of the points to be analysed, inches.

       NOTE: for applications to other parts of this thesis,
evaluations are made only at the outside sur-
face, but the program is capable of making
evaluations at interior points.

Card No. 5. Format F80.2

    a. Internal pressure, psi.

Card No. 6. Format 3F20.8

    a. Components of the force applied at the tip of the
pipe, vertical, sidewards and outwards from the
tip, so as to form a right handed set of orthogonal
axes, lbs.

Card No. 7. Format 3F20.8

    a. Components of the moment applied at the tip of the pipe,
in the same arrangement as for the forces, lb-inches.

Card No. 8. Format F80.2

    a. This is a sentinel card with one number on it. A
negative number indicates that the job is finished;
a zero or any positive number indicates that the
program will be rerun for another set of radial
distance and loads, in which case, cards similar to
No. 4 through 8 must follow this one.

OUTPUTS (all arguments are outputs)

  RO. External radius of the pipe.

  RI. Internal radius of the pipe.

  XE. Young's modulus of elasticity.

G.	Shear modulus of elasticity.
XNU.	Poisson's ratio.
SPECW.	Specific weight of the material.
D.	A constant evaluated when analysing shear stresses produced by shearing forces.
XL1.	A one dimensional array containing the distances from the tip to each cross section considered.
NPOINT.	Number of points analysed in each cross section.
AREA.	Cross sectional area of the pipe.
ALL1.	A three dimensional array intended to store the stresses at any of the points, in case the points are at the external surface of the pipe; otherwise, it has no meaning.

Other subroutines which are needed and listings for which are given in this Appendix are:

TORS:	used by CANTIL to compute shear stresses produced by torsional moments.
BEND:	used by CANTIL to compute bending stresses.
AXIAL:	used by CANTIL to compute stresses due to axial forces.
SHEAR:	used by CANTIL to compute shear stresses produced by shear forces.
CROSS:	computes the cross product of two vectors.
DOT:	computes the dot product of two vectors.
TIMES:	computes the product of a scalar and a vector.
PLUS:	computes the sum of two vectors.
MINUS:	computes the difference between two vectors.
TRANSF:	computes the components of a vector in another angularly displaced set of axes.

METHOD.

The vectorial approach discussed in reference 5 of this thesis is used to compute stresses produced at points of the cross section by internal pressure and forces and moments acting at the centroid of that cross section.
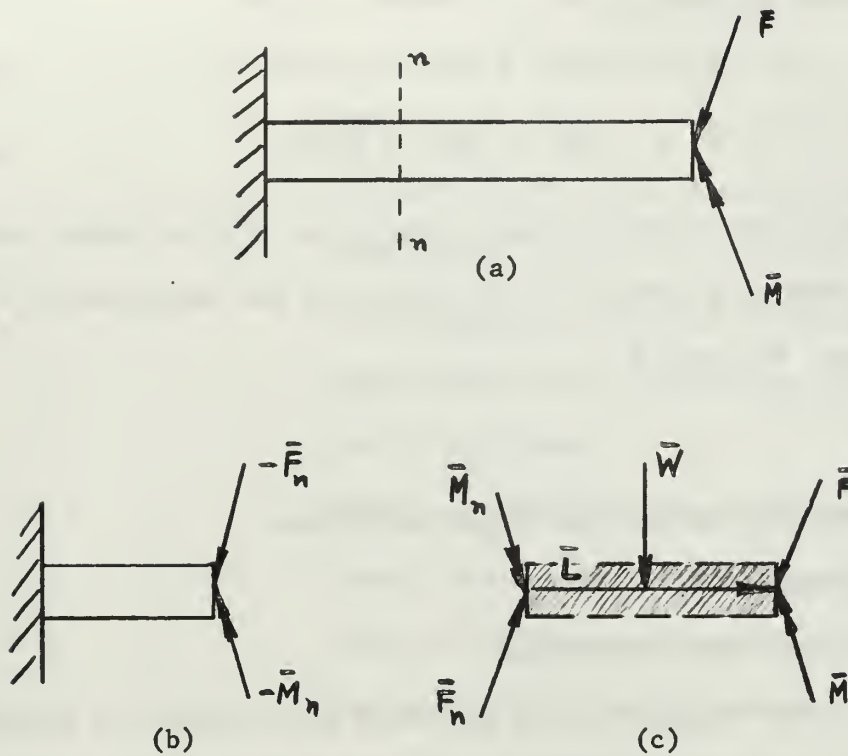
Fig. A-2.

Those forces and moments, in turn, are computed by the classical vectorial analysis of the statics of a beam. If the force $\bar{F}$ and the moment $\bar{M}$ are applied at one end of a beam, Fig. A.2.a., the force $\bar{F}_n$ and moment $\bar{M}_n$ acting at the centroid of the cross section nn, Fig. A.2.c., are found by considering the equilibrium of the segment of beam from the tip to the cross section. Summing forces and taking moments about the centroid of the cross section

$$\overline{F} + \overline{W} + \overline{F}_n = 0 \qquad\qquad (A.1)$$

$$\overline{M}_n + \overline{M} + \overline{L}x\overline{F} + \tfrac{1}{2}\overline{L}x\overline{W} = 0 \qquad\qquad (A.2)$$

where $\overline{L}$ is the vector distance from the centroid of the cross section to the point of application of the loads at the tip, and $\overline{W}$ is the force due to the weight of the segment of beam.

Solving for $\overline{F}_n$ and $\overline{M}_n$

$$\overline{F}_n = -(\overline{F} + \overline{W}) \qquad\qquad (A.3)$$

$$\overline{M}_n = -(\overline{M} + \overline{L}x\overline{F} + \tfrac{1}{2}\overline{L}x\overline{W}) \qquad\qquad (A.4)$$

The forces and moments acting at the cross section under considera-tion on the remaining portion of the beam, are the negatives of $\overline{F}_n$ and $\overline{M}_n$ found above, Fig. A.2.b.

PRINT-OUTS

The print-outs are several pages as follows

1st page.

a. Pipe dimensions

b. Computed cross sectional area, moment of inertia
    and polar moment of inertia of the cross section.

c. Material properties.

d. Number of points analysed in each cross section,
    number of cross sections analysed and their distances
    from the tip.

2nd page.

a. Radial distance of the points analysed .

b. Loads applied to the tip.

c. Distance from the tip to the first cross section
    analysed.

d.   Computed loads acting at that cross section

Following pages.   For each analysed point the print-out contains:

a.   Angular position of the point in the cross section
(degrees)

b.   Forces and moments acting at that cross section in
radial, tangential and axial components.

c.   Stresses produced by individual loads.

SHTZT is the shear stress in the ZT direction
produced by the axial component of the moment

SBZZ axial (ZZ direction) stress produced by
the tangential component of the moment.

SAZZ axial stress produced by the axial compon-
ent of the force.

SHFZR and SHFZT are stresses produced by the
radial and tangential components of the force.

SPRR and SPTT are radial and tangential stresses
produced by the internal pressure.

d.   If the analysed points are in the external surface
of the pipe, there will be additional print-outs of
the total axial, tangential and shear stresses at
the point.

Analysis of other cross sections for the initial and/or other radial
distance and tip loads and pressure produce similar outputs as described
from page 2 on.   The complete program and sample outputs of the analysis
made for points at the external surface and ½ in. under that surface of
cross sections 1 and 2 of the pipe shown in Fig. A.1., follow this page.

35

```
      SUBROUTINE CANTIL(RO,RI,XE,G,XNU,SPECW,D,XLL,NPOINT,AREA,ALL1)       CANT0010
C                                                                          CANT0020
C  TO FIND THE STATE OF STRESS AT ANY POINT IN A CANTILIVERED STRAIGHT     CANT0030
C  PIPE OF CONCENTRIC BORE, LOADED AT THE TIP BY GENERAL FORCES AND        CANT0040
C  MOMENTS AND WITH INTERNAL PRESSURE.                                     CANT0050
C                                                                          CANT0060
      DIMENSION AF(3),AXM(3),F(3),XM(3),R(3),ER(3),ET(3),EZ(3),           CANT0070
     1 SHTZT(3),SBZZ(3),SAZZ(3),SHFZR(3),SHFZT(3),SPRR(3),SPTT(3),        CANT0080
      DIMENSION E(3),A1(3),A2(3),A3(3),A4(3),XL1(5),XL2(3),               CANT0090
     1 AXMI(3),ALL1(3,36,5),AFI(3),FWGHT(3)                               CANT0100
C                                                                          CANT0110
      PRINT 500                                                            CANT0120
  500 FORMAT( 1H1 )                                                        CANT0130
C                                                                          CANT0140
C  PIPE DIMENSIONS.  DO,DI, AND XL ARE EXTERNAL AND INTERNAL DIAMETERS     CANT0150
C  AND PIPE LENGTH RESPECTIVELY.                                           CANT0160
C                                                                          CANT0170
   50 READ 50, DO, DI, XL                                                  CANT0180
      FORMAT( 3F20.8 )                                                     CANT0190
      WRITE(6,100) DO, DI, XL                                             CANT0200
  100 FORMAT( // 15X, 2CHEXTERNAL DIAMETER  =, F8.2, 7H INCHES /          CANT0210
     1           15X, 2OHINTERNAL DIAMETER  =, F8.2, 7H INCHES //         CANT0220
     2           15X, 2OHLENGTH             =, F8.2, 7H INCHES /// )       CANT0230
C                                                                          CANT0240
      RO = DO/2.0                                                          CANT0250
      RI = DI/2.0                                                          CANT0260
      RO2 = RO*RO                                                          CANT0270
      RI2 = RI*RI                                                          CANT0280
      PI = 3.14159265                                                      CANT0290
      AREA = PI*(RO2 - RI2 )                                               CANT0300
      ERTIA = AREA*(RO2 + RI2)/4.0                                         CANT0310
      POLER = 2.0*ERTIA                                                    CANT0320
C                                                                          CANT0330
      WRITE(6, 103) AREA, ERTIA, POLER                                     CANT0340
  103 FORMAT(   15X, 2OHCROSSECTIONAL AREA  =, F12.4, 4H IN2 /            CANT0350
     1           15X, 2OHMOMENT OF INERTIA  =, F12.4, 4H IN4 /            CANT0360
     2           15X, 2OHPOLAR MOMENT OF I. =, F12.4, 4H IN4 /// )        CANT0370
C                                                                          CANT0380
C  MATERIAL PROPERTIES. XE IS MODULUS OF ELASTICITY. G IS SHEAR MODULUS    CANT0390
C  OF ELASTICITY WHICH WILL BE COMPUTED IF NOT GIVEN. ALPHA IS COEFF. OF   CANT0400
C  THERMAL EXPANSION. IF NOT GIVEN, A PRINTOUT WILL SAY SO. XNU IS         CANT0410
C  POISSON RATIO. SPECW IS SPECIFIC WIGHT.                                 CANT0420
                                                                           CANT0430
```

```
C
      READ 51, XF, G, ALPHA, XNU, SPFCW                               CANT0440
   51 FORMAT( 3E20.8, 2F10.8 )                                        CANT0450
C                                                                     CANT0460
      PRINT 200, XF                                                   CANT0470
  200 FORMAT(15X,21HMODULUS OF ELASTICITY, 3X, E10.2, 4H PSI )        CANT0480
      IF ( G )3,3,4                                                   CANT0490
    3 G =XF/(2.0*( 1.0 + XNU ))                                       CANT0500
      PRINT 201, G                                                    CANT0510
    4 FORMAT(15X, 7HSHEAR MODULUS OF ELASTICITY, 3X, E10.2, 4H PSI )  CANT0520
  201 PRINT 202, ALPHA                                                CANT0530
      IF ( ALPHA ) 5, 5, 6                                            CANT0540
    5 FORMAT(15X, 42HCOEFFICIENT OF THERMAL EXPANSION NOT GIVEN )     CANT0550
  202 GO TO 7                                                         CANT0560
    6 PRINT 203, ALPHA                                                CANT0570
  203 FORMAT(15X, 32HCOEFFICIENT OF THERMAL EXPANSION, 3X, E10.2,     CANT0580
     1 13H IN/IN/DEGREE )                                             CANT0590
    7 WRITE(6,204) XNU, SPFCW                                         CANT0600
  204 FORMAT(15X, 13HPOISSON RATIO,3X, F6.3 /                         CANT0610
     1     15X, 15HSPECIFIC WEIGHT,3X, F8.4, 7H LB/IN3 /// )          CANT0620
C                                                                     CANT0630
C     NPOINT IS THE NUMBER OF POINTS TO BE ANALYSED IN EACH CROSS SECTION. CANT0640
C     NSECT IS THE NUMBER OF CROSS SECTIONS TO BE ANALYSED. XL1 IS ONE CANT0650
C     DIMENSIONAL ARRAY CONTAINING THE DISTANCES OF THE CROSS SECTIONS FROM CANT0660
C     THE TIP.                                                        CANT0670
C                                                                     CANT0680
      READ 54, NPOINT, NSECT, XL1                                     CANT0690
   54 FORMAT(2I5, 5F10.5 )                                            CANT0700
C                                                                     CANT0710
      WRITE(6,700) NPOINT, NSECT, XL1                                 CANT0720
  700 FORMAT(15X, 9HNUMBER OF POINTS TO ANALYSE ', I5 /               CANT0730
     1     15X, 2CHNUMBER OF SECTIONS TO ANALYZE, I5 /                CANT0740
     2     15X, 9HDISTANCES FROM THE TIP TO THE CROSS SECTIONS, INCHESCANT0750
     3 ', // 20X, 5F8.3 )                                             CANT0760
C                                                                     CANT0770
C     UNIT VECTORS IN POLAR DIRECTIONS                                CANT0780
C                                                                     CANT0790
      ER(1) = 1.0000                                                  CANT0800
      ER(2) = 0.0000                                                  CANT0810
      ER(3) = 0.0000                                                  CANT0820
      ET(1) = 0.0000                                                  CANT0830
      ET(2) = 1.0                                                     CANT0840
                                                                      CANT0850
                                                                      CANT0860
```

37

```
C
      ET(3) = 0.0                                                        CANT0870
      EZ(1) = 0.0                                                        CANT0880
      EZ(2) = 0.0                                                        CANT0890
      EZ(3) = 1.0                                                        CANT0900
C                                                                        CANT0910
C     DELTA IS THE ANGULAR INTERVAL IN DEGREES BETWEEN POINTS. R IS THE POS- CANT0920
C     ITION VECTOR OF THE POINT TO BE ANALYSED TAKING AS CENTER THE CENTER   CANT0930
C     OF THE CROSS SECTION. XL2 IS THE DISTANCE VECTOR FROM THE CENTER OF     CANT0940
C     THE CROSS SECTION TO THE TIP.                                     CANT0950
C                                                                        CANT0960
      DELTA = 360/NPOINT                                                 CANT0970
      THETA2 = PI/180.0                                                  CANT0980
C                                                                        CANT0990
   8  READ 900, R(1)                                                     CANT1000
  900 FORMAT( F80.2 )                                                    CANT1010
      R(2) = 0.0                                                         CANT1020
      R(3) = 0.0                                                         CANT1030
      XL2(1) = 0.0                                                       CANT1040
      XL2(2) = 0.0                                                       CANT1050
C                                                                        CANT1060
C     LOADS APPLIED IN VERTICAL DOWNWARDS (1), TRANSVERSE (2) AND AXIALLY CANT1070
C     OUTWARDS FROM THE TIP (3) DIRECTIONS. P IS THE INTERNAL PRESSURE.  CANT1080
C     AFL AND AXM1 ARE THE GENERAL FORCE AND GENERAL MOMENT ACTING AT THE CANT1090
C     TIP.                                                               CANT1100
C                                                                        CANT1110
   52 READ(5, 52) P, AFL, AXM1                                          CANT1120
      FORMAT( F80.2 / 3F20.8 / 3F20.8 )                                  CANT1130
C                                                                        CANT1140
C                                                                        CANT1150
      DO 11 J = 1, NSECT                                                 CANT1160
C                                                                        CANT1170
      PRINT 500                                                          CANT1180
      PRINT 901, R(1)                                                    CANT1190
  901 FORMAT(//15X,'RADIAL DISTANCE OF POINTS =',F12.5,' INCHES'///)     CANT1200
C                                                                        CANT1210
      PRINT 800                                                          CANT1220
  800 FORMAT(15X, 24HLOADS APPLIED TO THE TIP, / )                       CANT1230
      WRITE(6, 302) P, AFL, AXM1                                        CANT1240
  302 FORMAT(                                                            CANT1250
     1     15X, 20HINTERNAL PRESSURE  =,F12.2, 4H PSI /                  CANT1260
     2     15X, 20HAPPLIED FORCE   =, 3F12.2, 3H LB /                    CANT1270
           15X, 20HAPPLIED MOMENT  =, 3F12.2, 6H LB-IN /// )             CANT1280
                                                                         CANT1290
```

```
C
      XL2(3) = XL1(J)                                           CANTI1300
      PRINT 305, XL2(3)                                         CANTI1310
  305 FORMAT(15X,'DISTANCE FROM THE TIP TO THE CROSS SECTION',F10.2,  CANTI1320
     1 ' INCHES.')                                              CANTI1330
C                                                               CANTI1340
      PRINT 801                                                 CANTI1350
  801 FORMAT(//15X,'LOADS ACTING ON THE CROSS SECTION')         CANTI1360
C                                                               CANTI1370
C FWGHT IS THE FORCE DUE TO THE WEIGHT OF THE PIPE FROM THE TIP TO THE CANTI1380
C CROSS SECTION. AF AND AXM ARE THE LOADS ACTING ON THE CROSS SECTION. CANTI1390
C                                                               CANTI1400
      FWGHT(1) = AREA*SPECW*XL2(3)                              CANTI1410
      FWGHT(2) = 0.0                                            CANTI1420
      FWGHT(3) = 0.0                                            CANTI1430
      CALL PLUS( FWGHT, AF1, AF )                               CANTI1440
      CALL CROSS( XL2, AF1, AI )                                CANTI1450
      CALL PLUS( AXM1, AI, AXM )                                CANTI1460
      CALL TIMES( 0.5, XL2, A2 )                                CANTI1470
      CALL CROSS( A2, FWGHT, A3 )                               CANTI1480
      CALL PLUS ( AXM, A3, AXM )                                CANTI1490
C                                                               CANTI1500
      WRITE(6, 302) P, AF, AXM                                  CANTI1510
C                                                               CANTI1520
      INDEX = 1                                                 CANTI1530
      WRITE(6, 500)                                             CANTI1540
C                                                               CANTI1550
      DO 1 I = 1, NPOINT                                        CANTI1560
      AI = I                                                    CANTI1570
C                                                               CANTI1580
      IF( INDEX .LE. 4 ) GO TO 25                               CANTI1590
      INDEX = 1                                                 CANTI1600
      WRITE(6, 500)                                             CANTI1610
   25 INDEX = INDEX + 1                                         CANTI1620
C                                                               CANTI1630
C THETA1 IS THE ANGLE IN DEGREES FROM THE DOWNWARDS DIRECTION TO THE CANTI1640
C POINT TO BE ANALYSED, IN THE POSITIVE CCW DIRECTION. F AND XM ARE CANTI1650
C THE FORCE AND MOMENT ACTING ON THE CROSS SECTION, WITH COMPONENTS IN CANTI1660
C THE POLAR DIRECTIONS.                                         CANTI1670
C                                                               CANTI1680
      THETA1 = (AI - 1.0)*DELTA                                 CANTI0700
      PRINT 21, THETA1                                          CANTI1710
   21 FORMAT( // 15X, 7HTHETA =, F8.2, 3X, 7HDEGREES )          CANTI1720
C
```

39

```
C
        THETA = THETA1*THETA2                                          CANT1730
C
        CALL TRANSF( AF, THETA, F )                                    CANT1740
        CALL TRANSF(AXM, THETA, XM )                                   CANT1750
C
  620   WRITE(6, 600) F,XM                                             CANT1760
    1   FORMAT(   15X, 2OHTRANSFORMED FORCE =, 3E12.5, 3H LB /         CANT1770
                  15X, 2OHTRANSFORMED MOMENT =, 3E12.5, 6H LB-IN / )   CANT1780
C                                                                      CANT1790
C  SHTZT IS THE SHEAR STRESS IN THE ZT DIRECTION PRODUCED BY THE TORS- CANT1800
C  IONAL MOMENT. SBZZ IS THE STRESS IN THE AXIAL ZZ DIRECTION PRODUCED CANT1810
C  BY THE BENDING MOMENTS. SAZZ IS STRESS IN THE AXIAL ZZ DIRECTION PROD-CANT1820
C  UCED BY THE AXIAL FORCE. SHFZR AND SHFZT ARE THE SHEAR STRESSES PROD-CANT1830
C  UCED IN THE ZR AND ZT DIRECTIONS BY THE SHEAR FORCES. SPRR AND      CANT1840
C  SPTT ARE THE STRESSES IN THE RADIAL RR AND TANGENTIAL TT DIRECTIONS CANT1850
C  PRODUCED BY THE INTERNAL PRESSURE.                                  CANT1860
C                                                                      CANT1870
        CALL TORS(XM, R, EZ, ERTIA, SHTZT )                           CANT1880
C                                                                      CANT1890
        CALL BEND( XM, R, EZ, ERTIA, SBZZ )                           CANT1900
C                                                                      CANT1910
        CALL AXIAL( F, EZ, AREA, SAZZ )                                CANT1920
C                                                                      CANT1930
        CALL SHEAR( F,R,ER,ET,ERTIA,XNU,RI2,RO2,SHFZR,SHFZT,D)         CANT1940
C                                                                      CANT1950
        CALL PRESS(P, R, RI2, RO2, SPRR, SPTT )                        CANT1960
C                                                                      CANT1970
   21   WRITE(6, 22) SHTZT(2),SBZZ(3),SAZZ(3),SHFZR(1),SHFZT(2),       CANT1980
        SPRR(1),SPTT(2)                                               CANT1990
   22   FORMAT(15X,5HSHTZT,     E17.5/                                 CANT2000
    1          15X, 5H BZZ,     E17.5/                                 CANT2010
    2          15X, 5H AZZ,     E17.5/                                 CANT2020
    3          15X, 5HSHFZR,    E17.5/                                 CANT2030
    4          15X, 5HSHFZT,    E17.5/                                 CANT2040
    5          15X, 5H PRR,     E17.5/                                 CANT2050
    6          15X, 5H PTT,     E17.5/ )                               CANT2060
C                                                                      CANT2070
 1002   IF( R(1) - RO ) 1001, 1002, 1001                              CANT2080
 1001   CONTINUE                                                       CANT2090
C                                                                      CANT2100
C  ALL IS AN ARRAY INTENDED TO MEMORIZE THE STRESSES AT ANY ONE OF THE CANT2110
C  POINTS IN CASE THOSE POINTS ARE AT THE EXTERNAL SURFACE OF THE PIPE.CANT2120
```

40

```
C     OTHERWISE, IT HAS NO MEANING.                                      CANT2160C
C     ALLI(1,.,) ARE STRESSES IN THE TANGENTIAL TT DIRECTION.            CANT2170C
C     ALLI(2,.,) ARE STRESSES IN THE AXIAL ZZ DIRECTION.                 CANT2180C
C     ALLI(3,.,) ARE SHEAR STRESSES IN THE ZT DIRECTION.                 CANT2190C
C                                                                        CANT2200C
      ALLI(1,I,J) = SPTT(2)                                              CANT2210C
      ALLI(2,I,J) = SBZZ(3) + SAZZ(3)                                    CANT2220C
      ALLI(3,I,J) = SHFZT(2) + SHTZT(2)                                  CANT2230C
C                                                                        CANT2240C
      PRINT 31                                                           CANT2250C
   31 FORMAT(/ 27X, 13HT'T DIRECTION, 4X, 13HZ'Z DIRECTION, 4X, 13HZ'T   CANT2260C
     1DIRECTION )                                                        CANT2270C
C                                                                        CANT2280C
      PRINT 32,( K, I, J, K = 1, 3 )                                     CANT2290C
   32 FORMAT( 23X,3( 5HALLI(, I1, 1H,, I2, 1H,, I1, 1H),5X) )            CANT2300C
C                                                                        CANT2310C
      PRINT 33,( ALLI( K, I, J), K = 1, 3 )                             CANT2320C
   33 FORMAT( 15X, 'STRESSES', E16.5, 2E17.5 )                          CANT2330C
 1001 CONTINUE                                                           CANT2340C
C                                                                        CANT2350C
    1 CONTINUE                                                           CANT2360C
C                                                                        CANT2370C
   11 CONTINUE                                                           CANT2380C
C                                                                        CANT2390C
C     FIN IS A SENTINEL CARD. WHEN NOT NEGATIVE ( MAY BE A BLANK CARD ) THENCANT2400C
C     OTHER SET OF RADIAL DISTANCE AND TIP LOADS WILL BE READ AND THE    CANT2410C
C     PROGRAM WILL RERUN. IF FIN IS A NEGATIVE NUMBER, THE PROGRAM WILL  CANT2420C
.     PROCEDE TO THE NEXT STEP.                                          CANT2430C
C                                                                        CANT2440C
  501 READ 501, FIN                                                      CANT2450C
      FORMAT( F80.5 )                                                    CANT2460C
C                                                                        CANT2470C
  999 IF ( FIN ) 999, 8, 8                                               CANT2480C
      CONTINUE                                                           CANT2490C
      RETURN                                                             CANT2500C
      END                                                                CANT2510C
                                                                         CANT2520C
                                                                         CANT2530C
```

41

```
C      SUBROUTINE TORS(XM,R, EZ, ERTIA, STZT )                          TORS0010
C                                                                       TORS0020
C   TO FIND THE SHEAR STRESS PRODUCED BY THE TORSIONAL COMPONENT OF THE TORS0030
C   APPLIED MOMENT XM. R IS THE POSITION VECTOR OF THE POINT TO BE ANALYZEDTORS0040
C   EZ IS UNIT VECTOR IN THE AXIAL DIRECTION. ERTIA IS THE MOMENT OF IN- TORS0050
C   ERTIA. STZT IS THE PRODUCED SHEAR STRESS IN THE ZT DIRECTION.       TORS0060
C                                                                       TORS0070
       DIMENSION  XM(3), R(3), AL(3), EZ(3),  STZT(3)                   TORS0080
       CALL CROSS( EZ, R, AL )                                          TORS0090
       CALL DOT(XM, EZ, Z )                                             TORS0100
       CALL TIMES( Z/(2.0*ERTIA), AL, STZT )                            TORS0110
       RETURN                                                           TORS0120
       END                                                              TORS0130
```

42

```
C      SUBROUTINE BEND(XM, R, EZ, ERTIA, SBZZ )          BEND0010
C                                                        BEND0020
C  TO FIND THE STRESSES PRODUCED BY THE BENDING COMPONENT OF THE APPLIED  BEND0030
C  MOMENT XM. R IS THE POSITION VECTOR OF THE POINT TO BE ANALYZED. EZ  BEND0040
C  IS UNIT VECTOR IN THE AXIAL DIRECTION. ERTIA IS MOMENT OF INERTIA.  BEND0050
C  SBZZ IS STRESS PRODUCED IN THE AXIAL ZZ DIRECTION.   BEND0060
C                                                        BEND0070
       DIMENSION XM(3), R(3), EZ(3), A1(3), SBZZ(3)     BEND0080
       CALL CROSS( R, EZ, A1 )                          BEND0090
       CALL DOT( A1, XM, Z )                            BEND0100
       CALL TIMES( Z/ERTIA, EZ, SBZZ )                  BEND0110
       RETURN                                           BEND0120
       END                                              BEND0130
```

```
      SUBROUTINE AXIAL( F, EZ, AREA, SAZZ )                          AXIA0010
C                                                                    AXIA0020
C  TO FIND THE STRESSES PRODUCED BY THE AXIAL COMPONENT OF THE APPLIED AXIA0030
C  FORCE F. EZ IS UNIT VECTOR IN THE AXIAL DIRECTION. AREA IS THE AREA AXIA0040
C  OF THE CROSS SECTION. SAZZ IS THE STRESS PRODUCED IN THE AXIAL ZZ  AXIA0050
C  DIRECTION                                                         AXIA0060
C                                                                    AXIA0070
      DIMENSION F(3), EZ(3), A1(3), SAZZ(3)                          AXIA0080
      CALL DOT( F, EZ, Z )                                           AXIA0090
      CALL TIMES( Z/AREA, EZ, SAZZ )                                 AXIA0100
      RETURN                                                         AXIA0110
      END                                                            AXIA0120
```

```
      SUBROUTINE SHEAR(F,R,ER,ET,ERTIA,XNU,RI2,RO2,SHFRZ,SHFTZ, D )     SHEA0010
C                                                                       SHEA0020
C   TO FIND THE SHEAR PRODUCED BY THE TRANSVERSE COMPONENTS OF THE APPLIEDSHEA0030
C   FORCE F. R IS POSITION VECTOR OF THE POINT TO BE ANALYZED. FR AND   SHEA0040
C   FT ARE UNIT VECTORS IN THE RADIAL AND TANGENTIAL DIRECTIONS. ERTIA  SHEA0050
C   IS MOMENT OF INERTIA OF THE CROSS SECTION. XNU IS POISSON RATIO. RI2 SHEA0060
C   AND RO2 ARE THE SQUARE OF THE INTERNAL AND EXTERNAL RADIUS OF THE   SHEA0070
C   CROSS SECTION. SHFRZ AND SHFTZ ARE THE SHEAR STRESSES PRODUCED IN THESHEA0080
C   RZ AND TZ DIRECTIONS. D IS A PARAMETER OUTPUT TO BE USED SOMEWHERE  SHEA0090
C   ELSE.                                                               SHEA0100
C                                                                       SHEA0110
      DIMENSION F(3), R(3), ER(3), ET(3), SHFRZ(3), SHFTZ(3)           SHEA0120
      CALL DOT( R, R, R2 )                                              SHEA0130
      ENE =XNU + 1.5                                                    SHEA0140
      ALPHA = ENE*( RI2 + RO2 ) - R2                                    SHEA0150
      BETA = ENE*( R2 + RI2*RO2/R2 ) - R2                               SHEA0160
      Z1 = 4.0*ERTIA*( 1.0 +XNU )                                       SHEA0170
      CC = ( BETA + ALPHA )/Z1                                          SHEA0180
      D = ( BETA + ALPHA )/Z1                                           SHEA0190
      CALL DOT( F, ER, Z )                                              SHEA0200
      CALL TIMES( -C*Z, ER, SHFRZ )                                     SHEA0210
      CALL DOT( F, ET, Z )                                              SHEA0220
      CALL TIMES( D*Z, ET, SHFTZ )                                      SHEA0230
      RETURN                                                            SHEA0240
      END                                                               SHEA0250
```

45

```
      SUBROUTINE PRESS(P, R, RI2, RO2, SPRR, SPTT )
C
C TO FIND THE STRESSES IN THE RADIAL AND TANGENTIAL DIRECTIONS PRODUCED
C BY THE INTERNAL PRESSURE P. R IS THE POSITION VECTOR OF THE POINT TO
C BE ANALYZED. RI2 AND RO2 ARE THE SQUARE OF THE INTERNAL AND EXTERNAL
C RADIUS OF THE CROSS SECTION. SPRR AND SPTT ARE THE STRESSES PRODUCED
C IN THE RADIAL AND TANGENTIAL DIRECTIONS.
C
      DIMENSION SPRR(3), SPTT(3), R(3)
      CALL DOT(R, R, R2 )
      Z1 = P*RI2/(RO2 - RI2 )
      Z1 = RO2/R2 *( 1.0 - Z1 )
      SPRR(1) = Z1*( 1.0 + Z1 )
      SPTT(2) = 0C.000
      SPRR(3) = 0O.000
      SPTT(1) = 0.0
      SPTT(3) = 0.
      RETURN
      END
```
PRES0010
PRES0020
PRES0030
PRES0040
PRES0050
PRES0060
PRES0070
PRES0080
PRES0090
PRES0100
PRES0110
PRES0120
PRES0130
PRES0140
PRES0150
PRES0160
PRES0170
PRES0180
PRES0190
PRES0200

```
C      SUBROUTINE CROSS( A, B, C )                          CROS0010
C                                                           CROS0020
C  VECTOR PRODUCT OF VECTORS A AND B RESULTING VECTOR C.    CROS0030
C                                                           CROS0040
       DIMENSION A(3), B(3), C(3)                           CROS0050
       C(1) = A(2)*B(3) - A(3)*B(2)                         CROS0060
       C(2) = -A(1)*B(3) + A(3)*B(1)                        CROS0070
       C(3) = A(1)*B(2) - A(2)*B(1)                         CROS0080
       RETURN                                               CROS0090
       END                                                  CROS0100
```

47

```
C     SUBROUTINE DOT( A, B, C )                          DOT 0010
C  SCALAR PRODUCT OF VECTORS A AND B RESULTING C.        DOT 0020
C                                                        DOT 0030
      DIMENSION A(3), B(3)                               DOT 0040
      C = A(1)*B(1) +A(2)*B(2) + A(3)*B(3)               DOT 0050
      RETURN                                             DOT 0060
      END                                                DOT 0070
                                                         DOT 0080
```

48

```
C     SUBROUTINE TIMES( A, B, C )                        TIME0001
C                                                        TIME0002
C MULTIPLICATION OF THE SCALAR A WITH THE VECTOR B RESULTING VECTOR C.   TIME0003
C                                                        TIME0004
      DIMENSION B(3), C(3)                               TIME0005
      DO 1 J = 1,3                                       TIME0006
    1 C(J) = A*B(J)                                      TIME0007
      RETURN                                             TIME0008
      END                                                TIME0009
```

49

```
      SUBROUTINE PLUS( A, B, C )
C ADD VECTORS A AND B RESULTING C.
C
      DIMENSION A(3), B(3), C(3)
      DO 1 J = 1, 3
    1 C(J) = A(J) + B(J)
      RETURN
      END
```

```
PLUS0010
PLUS0020
PLUS0030
PLUS0040
PLUS0050
PLUS0060
PLUS0070
PLUS0080
PLUS0090
```

50

```
C     SUBROUTINE MINUS(A, B, C)                              MINU00010
C SUBSTRACT VECTOR B FROM VECTOR A RESULTING VECTOR C.       MINU00020
C                                                            MINU00030
      DIMENSION A(3), B(3), C(3)                             MINU00040
      DO 1 J = 1, 3                                          MINU00050
    1 C(J) = A(J) - B(J)                                     MINU00060
      RETURN                                                 MINU00070
      END                                                    MINU00080
                                                             MINU00090
```

51

```
C     SUBROUTINE TRANSF(A, THETA, C )                          TRAN00100
C                                                              TRAN00020
C TO FIND COMPONENTS OF VECTOR A IN OTHER AXIS ROTATED BY AN ANGLE  TRAN00030
C THETA. A IS CALLED C IN THE NEW AXIS.                        TRAN00040
C                                                              TRAN00050
      DIMENSION A(3), E(3,3), C(3)                             TRAN00060
      E(1,1) = COS(THETA)                                      TRAN00070
      E(2,1) = SIN(THETA)                                      TRAN00080
      E(3,1) = 0.0                                             TRAN00090
      E(1,2) = -SIN(THETA)                                     TRAN00100
      E(2,2) = COS(THETA)                                      TRAN00110
      E(3,2) = 0.00                                            TRAN00120
      E(1,3) = 0.00                                            TRAN00130
      E(2,3) = 0.0                                             TRAN00140
      E(3,3) = 1.0                                             TRAN00150
      DO 1 I = 1, 3                                            TRAN00160
      C(I) = 0.0                                               TRAN00170
      DO 1 J = 1, 3                                            TRAN00180
    1 C(I) = C(I) + A(J)*E(J,I)                                TRAN00190
      RETURN                                                   TRAN00200
      END                                                      TRAN00210
```

52

```
EXTERNAL DIAMETER   =    12.00  INCHES
INTERNAL DIAMETER   =    10.00  INCHES
LENGTH              =    90.00  INCHES


CROSSECTIONAL AREA  =      34.5575  IN2
MOMENT OF INERTIA   =     527.0020  IN4
POLAR MOMENT OF I.  =    1054.0039  IN4


MODULUS OF ELASTICITY       0.30E 08 PSI
SHEAR MODULUS OF ELASTICITY      0.12E 08 PSI
COEFFICIENT OF THERMAL EXPANSION NOT GIVEN
POISSON RATIO     0.300
SPECIFIC WEIGHT        0.2830 LB/IN3


NUMBER OF POINTS TO ANALYSE      12
NUMBER OF SECTIONS TO ANALYZE     2
DISTANCES FROM THE TIP TO THE CROSS SECTIONS, INCHES

     30.000  60.000   0.0       0.0       0.0
```

RADIAL DISTANCE OF POINTS =   6.00000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   100.00   100.00   100.00 LB
APPLIED MOMENT   =   100.00   100.00   100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION   30.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   393.39   100.00   100.00 LB
APPLIED MOMENT   =   -2900.00   7500.89   100.00 LB-IN

```
THETA =     0.0     DEGREES
TRANSFORMED FORCE  = 0.39339E 03 0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.29000E 04 0.75000E 04 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S RZZ       -0.35399E 02
S AZZ        0.28937E 01
SHEZR        0.0
SHEZT        0.53861E 01
S PRR        0.0
S PTT        0.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1, 1,1)       ALL1(2, 1,1)       ALL1(3, 1,1)
STRESSES     0.45455E 03       -0.82505E 02        0.59553E 01


THETA =    30.00     DEGREES
TRANSFORMED FORCE  = 0.39069E 03-0.11009E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.12390E 04 0.79460E 04 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S RZZ       -0.90466E 02
S AZZ        0.28937E 01
SHEZR        0.0
SHEZT       -0.59297E 01
S PRR        0.0
S PTT        0.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1, 2,1)       ALL1(2, 2,1)       ALL1(3, 2,1)
STRESSES     0.45455E 03       -0.87572E 02       -0.53605E 01


THETA =    60.00     DEGREES
TRANSFORMED FORCE  = 0.28330E 03-0.29069E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.50460E 04 0.62619E 04 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S RZZ       -0.71293E 02
S AZZ        0.28937E 01
SHEZR        0.0
SHEZT       -0.15657E 02
S PRR        0.0
S PTT        0.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1, 3,1)       ALL1(2, 3,1)       ALL1(3, 3,1)
STRESSES     0.45455E 03       -0.68399E 02       -0.15087E 02


THETA =    90.00     DEGREES
TRANSFORMED FORCE  = 0.10000E 03-0.39339E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.75000E 04 0.29000E 04 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S RZZ       -0.33017E 02
S AZZ        0.28937E 01
SHEZR        0.0
SHEZT       -0.21183E 02
S PRR        0.0
S PTT        0.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1, 4,1)       ALL1(2, 4,1)       ALL1(3, 4,1)
STRESSES     0.45455E 03       -0.30123E 02       -0.20619E 02
```

```
THETA =  120.00    DEGREES
TRANSFORMED FORCE   =-0.11009E 03-0.39069E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.79460E 04-0.12390E 04 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S BZZ        0.14106E 02
S AZZ        0.28937E 01
SHFZR        0.0
SHFZT       -0.21043E 02
S PRR        0.0
S PTT        0.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1, 5,1)       ALL1(2, 5,1)       ALL1(3, 5,1)
STRESSES     0.45455E 03        0.16999E 02        -0.20473E 02


THETA =  150.00    DEGREES
TRANSFORMED FORCE   =-0.29069E 03-0.28330E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.62619E 04-0.50460E 04 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S BZZ        0.57449E 02
S AZZ        0.28937E 01
SHFZR        0.0
SHFZT       -0.15259E 02
S PRR        0.0
S PTT        0.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1, 6,1)       ALL1(2, 6,1)       ALL1(3, 6,1)
STRESSES     0.45455E 03        0.60343E 02        -0.14689E 02


THETA =  180.00    DEGREES
TRANSFORMED FORCE   =-0.39339E 03-0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.29000E 04-0.75009E 04 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S BZZ        0.85399E 02
S AZZ        0.28937E 01
SHFZR        0.0
SHFZT       -0.53861E 01
S PRR        0.0
S PTT        0.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1, 7,1)       ALL1(2, 7,1)       ALL1(3, 7,1)
STRESSES     0.45455E 03        0.88292E 02        -0.48168E 01


THETA =  210.00    DEGREES
TRANSFORMED FORCE   =-0.39069E 03 0.11009E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.12390E 04-0.79460E 04 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S BZZ        0.90466E 02
S AZZ        0.28937E 01
SHFZR        0.0
SHFZT        0.53297E 01
S PRR        0.0
S PTT        0.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1, 8,1)       ALL1(2, 8,1)       ALL1(3, 8,1)
STRESSES     0.45455E 03        0.93360E 02        0.64989E 01
```

```
THETA =  240.00    DEGREES
TRANSFORMED FORCE  =-C.28330E 03 0.29069E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-C.50459E 04-0.62619E 04 0.10000E 03 LB-IN

SHTZT        C.56926E CC
S BZZ        0.71293E 02
S AZZ        C.28937E 01
SHFZR        0.0
SHFZT        0.15657E 02
S PER        0.0
S PTT        0.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1, 9,1)       ALL1(2, 9,1)       ALL1(3, 9,1)
STRESSES     0.45455E 03        0.74187E 02        0.16226E 02


THETA =  270.00    DEGREES
TRANSFORMED FORCE  =-C.10000E 03 0.39339E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-C.75009E 04-0.29000E 04 0.10000E 03 LB-IN

SHTZT        C.56926E CC
S BZZ        0.33017E 02
S AZZ        C.28937E 01
SHFZR        0.0
SHFZT        C.21188E 02
S PER        0.0
S PTT        C.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1,10,1)       ALL1(2,10,1)       ALL1(3,10,1)
STRESSES     0.45455E 03        C.35911E 02        C.21758E 02


THETA =  300.00    DEGREES
TRANSFORMED FORCE  = C.11009E 03 0.39069E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-C.79460E 04 0.12390E 04 0.10000E 03 LB-IN

SHTZT        0.56926E CC
S BZZ       -0.14106E 02
S AZZ        C.28937E 01
SHFZR        C.0
SHFZT        0.21043E 02
S PRK        0.0
S PTT        C.45455E C3

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1,11,1)       ALL1(2,11,1)       ALL1(3,11,1)
STRESSES     C.45455E C3       -0.11212E 02        0.21612E 02


THETA =  330.00    DEGREES
TRANSFORMED FORCE  = C.29069E 03 0.28330E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-C.62619E 04 0.50459E 04 0.10000E 03 LB-IN

SHTZT        0.56926E OC
S BZZ       -C.57449E 02
S AZZ        C.28937E 01
SHFZR        C.0
SHFZT        C.15259E 02
S FER        C.0
S PTT        0.45455E 03

             T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
             ALL1(1,12,1)       ALL1(2,12,1)       ALL1(3,12,1)
STRESSES     0.45455E 03       -0.54555E 02        0.15828E 02
```

RADIAL DISTANCE OF POINTS =   6.00000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   100.00   100.00   100.00 LB
APPLIED MOMENT   =   100.00   100.00   100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION   60.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   686.79   100.00   100.00 LB
APPLIED MOMENT   =   -5900.00   23703.59   100.00 LB-IN

```
THETA =      0.0    DEGREES
TRANSFORMED FORCE  = C.68679E 03 0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-C.59000E 04 0.23704E 05 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S BZZ        -0.26987E 03
S AZZ         C.28937E 01
SHFZR         C.0
SHFZT         0.53861E 01
S PRR         C.0
S PTT         0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
              ALL1(1, 1,2)       ALL1(2, 1,2)       ALL1(3, 1,2)
STRESSES      0.45455E 03       -0.26698E 03        0.59553E 01


THETA =     30.00   DEGREES
TRANSFORMED FORCE  = C.64477E 03-0.25679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = C.67422E 04 0.23478E 05 0.10000E 03 LB-IN

SHTZT         C.56926E 00
S BZZ        -C.26730E 03
S AZZ         C.28937E 01
SHFZR         0.0
SHFZT        -0.13831F 02
S PRR         0.0
S PTT         0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
              ALL1(1, 2,2)       ALL1(2, 2,2)       ALL1(3, 2,2)
STRESSES      0.45455E 03       -0.26441E 03       -0.13262E 02


THETA =     60.00   DEGREES
TRANSFORMED FORCE  = C.43000E 03-0.54477E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.17578E 05 0.16961E 05 0.10000F 03 LB-IN

SHTZT         0.56926E 00
S BZZ        -0.19311E 03
S AZZ         0.28937E 01
SHFZR         0.0
SHFZT        -0.29342E 02
S PRR         0.0
S PTT         0.45455F 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
              ALL1(1, 3,2)       ALL1(2, 3,2)       ALL1(3, 3,2)
STRESSES      0.45455E 03       -0.19021E 03       -C.28773E 02


THETA =     90.00   DEGREES
TRANSFORMED FORCE  = C.10000E 03-0.68679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.23704E 05 0.59000E 04 0.10000E 03 LB-IN

SHTZT         C.56926E 00
S BZZ        -C.67173F 02
S AZZ         0.28937E 01
SHFZR         C.0
SHFZT        -0.36991E 02
S PRR         0.0
S PTT        -0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
              ALL1(1, 4,2)       ALL1(2, 4,2)       ALL1(3, 4,2)
STRESSES      0.45455F 03       -0.64279E 02       -0.36421E 02
```

RADIAL DISTANCE OF POINTS =   5.50000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   100.00   100.00   100.00 LB
APPLIED MOMENT   =   100.00   100.00   100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION   30.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   393.39   100.00   100.00 LB
APPLIED MOMENT   =   -2900.00   7500.89   100.00 LB-IN

```
THETA =   120.00    DEGREES
TRANSFORMED FORCE  =-0.11009E 03-0.39069E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.79460E 04-0.12390E 04 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ          0.12930E 02
S AZZ          0.28937E 01
SHEZR         -0.72164E-01
SHEZT         -0.22426E 02
S PRR         -0.43201E 02
S PTT          0.49775E 03


THETA =   150.00    DEGREES
TRANSFORMED FORCE  =-0.29069E 03-0.28330E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.62619E 04-0.50460E 04 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ          0.52662E 02
S AZZ          0.28937E 01
SHEZR         -0.19054E 00
SHEZT         -0.16262E 02
S PRR         -0.43201E 02
S PTT          0.49775E 03


THETA =   180.00    DEGREES
TRANSFORMED FORCE  =-0.39330E 03-0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.29000E 04-0.75000E 04 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ          0.78282E 02
S AZZ          0.28937E 01
SHEZR         -0.25786E 00
SHEZT         -0.57402E 01
S PRR         -0.43201E 02
S PTT          0.49775E 03


THETA =   210.00    DEGREES
TRANSFORMED FORCE  =-0.39069E 03 0.11009E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.12390E 04-0.79460E 04 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ          0.92927E 02
S AZZ          0.28937E 01
SHEZR         -0.25609E 00
SHEZT          0.63195E 01
S PRR         -0.43201E 02
S PTT          0.49775E 03
```

RADIAL DISTANCE OF POINTS =   5.50000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   100.00   100.00   100.00 LB
APPLIED MOMENT   =   100.00   100.00   100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION   60.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =   100.00 PSI
APPLIED FORCE   =   686.79   100.00   100.00 LB
APPLIED MOMENT   =   -5900.00   23703.59   100.00 LB-IN

```
THETA =      0.0      DEGREES
TRANSFORMED FORCE   = 0.68679E 03 0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.59000E 04 0.23704E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S RZZ       -0.24738E 03
S AZZ        0.28937E 01
SHEZR        0.45018E 00
SHEZT        0.57402E 01
S PPR       -0.43201E 02
S PTT        0.49775E 03


THETA =     30.00     DEGREES
TRANSFORMED FORCE   = 0.64477E 03-0.25679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.67422E 04 0.23479E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ       -0.24502E 03
S AZZ        0.28937E 01
SHEZR        0.42264E 00
SHEZT       -0.14743E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =     60.00     DEGREES
TRANSFORMED FORCE   = 0.43000E 03-0.54477E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.17579E 05 0.16961E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ       -0.17702E 03
S AZZ        0.28937E 01
SHEZR        0.23186E 00
SHEZT       -0.31271E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =     90.00     DEGREES
TRANSFORMED FORCE   = 0.10000E 03-0.68679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.23704E 05 0.59000E 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ       -0.61575E 02
S AZZ        0.28937E 01
SHEZR        0.65549E-01
SHEZT       -0.39423E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03
```

```
THETA =  120.00   DEGREES
TRANSFORMED FORCE  =-0.25679E 03-0.64477E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.23478E 05-0.67422E 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.70364E 02
S AZZ        0.28937E 01
SHFZR       -0.16832E 00
SHFZT       -0.37011E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =  150.00   DEGREES
TRANSFORMED FORCE  =-0.54477E 03-0.43000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.16961E 05-0.17578E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.18345E 03
S AZZ        0.28937E 01
SHFZR       -0.35709E 00
SHFZT       -0.24682E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =  180.00   DEGREES
TRANSFORMED FORCE  =-0.68679E 03-0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.59000E 04-0.23704E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.24738E 03
S AZZ        0.28937E 01
SHFZR       -0.45018E 00
SHFZT       -0.57402E 01
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =  210.00   DEGREES
TRANSFORMED FORCE  =-0.64477E 03 0.25679E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.67422E 04-0.23478E 05 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.24502E 03
S AZZ        0.28937E 01
SHFZR       -0.42264E 00
SHFZT        0.14740E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03
```

```
THETA =  240.00    DEGREES
TRANSFORMED FORCE  =-0.43000E 03 0.54477E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.17578E 05-0.16961E 05 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ          0.17702E 03
S AZZ          0.28937E 01
SHFZR         -0.28186E 00
SHFZT          0.31271E 02
S PRR         -0.43201E 02
S PTT          0.49775E 03


THETA =  270.00    DEGREES
TRANSFORMED FORCE  =-0.10000E 03 0.68679E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.23704E 05-0.59000E 04 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ          0.61575E 02
S AZZ          0.28937E 01
SHFZR         -0.65549E-01
SHFZT          0.39423E 02
S PRR         -0.43201E 02
S PTT          0.49775E 03


THETA =  300.00    DEGREES
TRANSFORMED FORCE  = 0.25679E 03 0.64477E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.23478E 05 0.67422E 04 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ         -0.70364E 02
S AZZ          0.28937E 01
SHFZR          0.16832E 00
SHFZT          0.37011E 02
S PRR         -0.43201E 02
S PTT          0.49775E 03


THETA =  330.00    DEGREES
TRANSFORMED FORCE  = 0.54477E 03 0.43000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.16961E 05 0.17578E 05 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ         -0.18345E 03
S AZZ          0.28937E 01
SHFZR          0.35709E 00
SHFZT          0.24682E 02
S PRR         -0.43201E 02
S PTT          0.49775E 03
```

DIGITAL COMPUTER PROGRAM FOR SECTION 2 AND NUMERICAL RESULTS

The programs presented herein provide a method for applying the theory developed in Section 2 of this thesis. Actual situations can be handled by subroutines ZULIA, GUAYRA, CUMANA and DSIMQ (DSIMQ is presented in Appendix D). Simulated situations require in addition subroutines CANTIL presented in Appendix A, and TIUNA and BLANCA presented in this Appendix. The last of the subroutines mentioned is an adaptation of a subroutine taken from reference 7 of this thesis.

ZULIA is used to specify the required information, such as material properties, number of Fourier coefficients to be computed and description of the arrangement of strain gage elements and their transverse sensitivity factor. Enough self explanatory comment statements have been included which specify the introduction of the information. Print-out statements present the information received for processing. Once the information is properly arranged, subroutine GUAYRA is used to make the required computations.

The sequence in GUAYRA follows closely the theoretical development of the method. It has sufficient comment statements separating blocks of computer processing instructions as to follow the theoretical procedure. Print-out statements present the computed Fourier coefficients.

CUMANA is used by GUAYRA for auxiliary computations.

Use of the subroutines is made by a very brief main program TERESITA. This program merely dimensions the various subroutines and turns control over to subroutine ZULIA. The card arrangement of the source deck is as shown in Fig. B.1.

Some sample results of the application of the program as specified at the end of Section 2, follow the card listings of the programs.

Deck of data

//GO.SYSIN DD*

/*

Block of subprograms

Main program deck

FORT.SYSIN DD*

//TAB EXEC FORTCLG

//TERESITA JOB '0324','JESUS A. TABORDA',MSGLEVEL=1
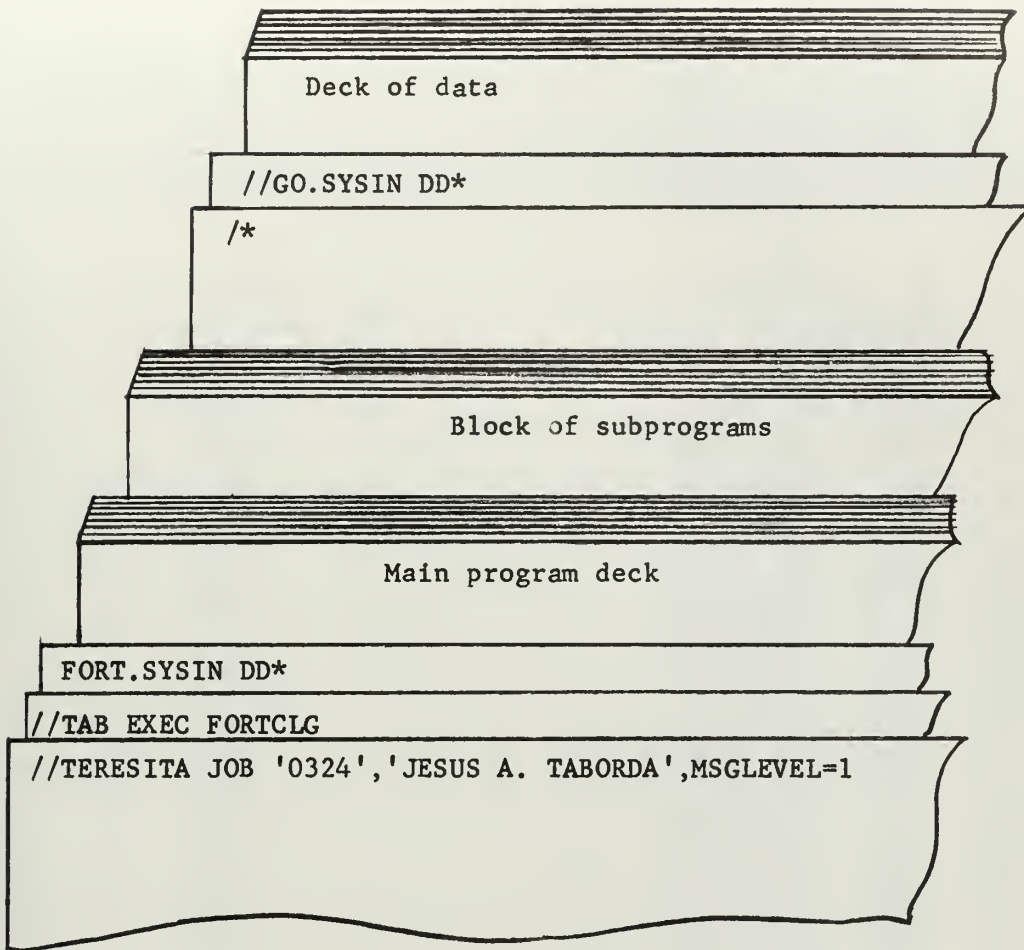
Fig. B.1

```
//TERESITA JOB '0324','TABORDA, JESUS A.',MSGLEVEL=1          00000010
//TAB  EXEC FORTCLG
//FORT EXEC PGM=IFYFORT

      DIMENSION Z1(36), Z2(36), Z3(37), Z4(37), Z5(36,36), Z6(36,36)  ZULIA
      DIMENSION STRNEX(36),FSET(36,36),HSET(36),A(36),B(36),          GUAYRA
     1 C(36),ST(360),SL(360),SH(360),STA(10),STB(10),SLA(10),         GUAYRA
     2 SLB(10),SHA(10),SHB(10),                                       GUAYRA
      DIMENSION AFL(3),AXMI(3),AF(3),AXM(3),F(3),XM(3),FWGHT(3),      CANTIL
     1 XL1(5),XL2(3),ER(3),ET(3),EZ(3),R(3),ALL1(3,360,5),           CANTIL
     2 SHFZT(3),SBZZ(3),SAZZ(3),SHFZR(3),SHFZT(3),SPRR(3),SPTT(3)     CANTIL
      DIMENSION A1(3),A2(3),A3(3),A4(3),F3(3),F4(3),F5(3),F6(3),      TRANSF
     1 XM3(3),XM4(3),XM5(3),XM6(3),R1(3),B2(3),B3(3),B4(3),B5(3),B6(3), SCRATCH
     2 C1(36,36),C2(36,36),C3(36,36),C4(36,36),C5(36), C6(36)         SCRATCH
                                                                      SCRATCH

      CALL ZULIA

      END
```

CC CC

68

```
      SUBROUTINE ZULIA

      DIMENSION T(36),P(36),R(36,36),W(36),ALL1(3,360,5),
     1 STRNFX(36), PI(37), TI(37), ZZ(36), NRAD(36)

C  SPECIFY NUMBER OF FOURIER COEFFICIENTS NCOEFF, NUMBER OF GAGE
C  ELEMENTS NGAGES, TRANSVERSE SENSITIVITY FACTOR TRANSV, AND COR-
C  RESPONDING TI) AND ANGULAR POSITION IN THE CROSS SECTION (CONTAINED IN THE
C  ARRAY TI) AND ANGULAR ORIENTATION FROM TANGENTIAL AXIS (CONTAINED
C  IN ARRAY PI).

5000  NCOEFF = 5
      NGAGES = 36, 3
      TRANSV = 1
      TRAN = TRANSV*100.0
      DO 5001 I = 1, 36, 3
      PI(I) = 0.0
      PI(I+1) = 60.0
      PI(I+2) = 120.0
      TI(I) = K*30
      TI(I+1) = TI(I)
5001  TI(I+2) = TI(I)
      K = 1

C  SET ANGLE PI(I) OF GAGE ELEMENTS FUNCTIONING IMPROPERLY TO 1.0F6
C  AND ELIMINATE THOSE. NUMBER OF EACH OF THE ELIMINATED ELEMENTS WILL
C  BE CONTAINED IN ARRAY NBAD FOR PRINT-OUT PURPOSES. ANGULAR POSITION
C  AND ORIENTATION OF THE REMAINING ACTIVE ELEMENTS WILL BE CONTAINED
C  IN ARRAYS T AND P RESPECTIVELY.

      PI(12) = 1.0F6
      PI(22) = 1.0F6
      PI(24) = 1.0F6
      PI(25) = 1.0F6
      PI(33) = 1.0F6
26    K = 0
      DO 33 I = 1, NGAGES
      IF( PI(I) .GE. 1.0F6 ) GO TO 34
      K = K+1
      P(K) = PI(I)
33    T(K) = TI(I)
```

```
34    GO TO 3
      L = L + 1
      NBAC(L) = 1
3     CONTINUE

C     SPECIFY MATERIAL PROPERTIES: YOUNG'S MODULUS OF ELASTICITY XE, SHEAR
C     MODULUS OF ELASTICITY G, POISSON'S RATIO XNU.

C     IF THE MATHEMATICAL MODEL OF A PIPE IS USED, OUTPUTS ARGUMENTS OF
C     SUBROUTINE CANTIL WILL DO IT.

      CALL    CANTIL(RG,RI,XE,G,XNU,SPECW,D,XL1,NPOINT,ARFA,ALL1)

C     SPECIFY READINGS OF THE GAGE ELEMENTS, TO BE CONTAINED IN ARRAY
C     STRNEX.

C     THEORETICAL READINGS CAN BE OBTAINED FROM THE OUTPUT OF SUBROUTINE
C     TIUNA. THIS USES AS INFORMATION THE MATERIAL PROPERTIES AND ANGULAR
C     ORIENTATION OF EACH ELEMENT, AND THE STRESS COMPONENTS AT EACH
C     ELEMENT CENTER. THIS IS OBTAINED FROM THE OUTPUT ALL1 OF CANTIL
C     REQUIERING THE ANGULAR POSITION IN THE CROSS SECTION AND THE CROSS
C     SECTION NUMBER TO IDENTIFY THE RIGHT STRESSES.

      NSECT = 1
      CALL TIUNA(XE,G,XNU,NSECT,ALL1,K,T,P,ZZ,TRANSV)

C     RANDOM ERRORS CAN BE ADDED TO THE THEORETICAL READINGS OF THE
C     GAGES, THE OUTPUT ZZ OF TIUNA, BY USING SUBROUTINE BLANCA.
C     SPECIFY THE MULTIPLIER ALT TO OBTAIN (ALT)*(10%) MAXIMUN RANDOM
C     ERROR ADDED.

      ALT = 0.3
      CALL BLANCA(STRNEX,ZZ,K,ALT)

C     PRINT-OUT OF ALL THE INFORMATION OBTAINED UP TO NOW.

      WRITE(6,500)
500   FORMAT(1H1)
      WRITE(6,11) NCOEFF
11    FORMAT(7(/),15X,'EXPANSION WITH',I3,' FOURIER COEFFICIENTS'//)
```

```
ZULIA049
ZULIA050
ZULIA051
ZULIA052
ZULIA053
ZULIA054
ZULIA055
ZULIA056
ZULIA057
ZULIA058
ZULIA059
ZULIA060
ZULIA061
ZULIA062
ZULIA063
ZULIA064
ZULIA065
ZULIA066
ZULIA067
ZULIA068
ZULIA069
ZULIA070
ZULIA071
ZULIA072
ZULIA073
ZULIA074
ZULIA075
ZULIA076
ZULIA077
ZULIA078
ZULIA079
ZULIA080
ZULIA081
ZULIA082
ZULIA083
ZULIA084
ZULIA085
ZULIA086
ZULIA087
ZULIA088
ZULIA089
ZULIA090
ZULIA091
ZULIA092
ZULIA093
ZULIA094
ZULIA095
ZULIA096
```

```
      SUBROUTINE JULIA                                                  ZULIA0001
                                                                        ZULIA0002
      DIMENSION T(36),P(36),R(36,36),W(36),ALL(3,360,5),               ZULIA0003
     1 STRNFX(36), PI(37), TI(37), ZZ(36), NPAD(36)                    ZULIA0004
C                                                                       ZULIA0005
C SPECIFY NUMBER OF FOURIER COEFFICIENTS NCOEFF, NUMBER OF GAGE        ZULIA0006
C ELEMENTS NGAGES, TRANSVERSE SENSITIVITY FACTOR TRANSV, AND COR-     ZULIA0007
C RESPONDING ANGULAR POSITION IN THE CROSS SECTION (CONTAINED IN THE  ZULIA0008
C ARRAY PI) AND ANGULAR ORIENTATION FROM TANGENTIAL AXIS (CONTAINED   ZULIA0009
C IN ARRAY PI).                                                        ZULIA0010
                                                                        ZULIA0011
      NCOEFF =                                                          ZULIA0012
      NGAGES =                                                          ZULIA0013
      TRANSV =                                                          ZULIA0014
      TRANS1 = TRANSV*100.0                                            ZULIA0015
 5000 DO 5001 I = 1, 36, 3                                             ZULIA0016
      PI(I)   = 0.0                                                    ZULIA0017
      PI(I+1) = 120.0                                                  ZULIA0018
      PI(I+2) = 240.0                                                  ZULIA0019
      TI(I)   = 0.0                                                    ZULIA0020
      TI(I+1) =                                                        ZULIA0021
      TI(I+2) =                                                        ZULIA0022
 5001 K = K                                                            ZULIA0023
C                                                                       ZULIA0024
C SET ANGLE PI(I) OF GAGE ELEMENTS FUNCTIONING IMPROPERLY TO 1.0F6    ZULIA0025
C AND ELIMINATE THOSE. NUMBER FOR EACH OF THE ELIMINATED ELEMENTS WILL ZULIA0026
C BE CONTAINED IN ARRAY NBAD FOR PRINT-OUT PURPOSES. ANGULAR POSITION ZULIA0027
C AND ORIENTATION OF THE REMAINING ACTIVE ELEMENTS WILL BE CONTAINED  ZULIA0028
C IN ARRAYS P AND T RESPECTIVELY.                                     ZULIA0029
                                                                        ZULIA0030
      PI(2)  = 1.0F6                                                   ZULIA0031
      PI(24) = 1.0F6                                                   ZULIA0032
      PI(25) = 1.0F6                                                   ZULIA0033
      PI(33) = 1.0F6                                                   ZULIA0034
      K = 0                                                            ZULIA0035
   20 DO 3 I = 1, NGAGES                                               ZULIA0036
      IF( PI(I) .GE. 1.0F6 ) GO TO 34                                 ZULIA0037
   33 K = K + 1                                                        ZULIA0038
      P(K) = PI(I)                                                     ZULIA0039
      T(K) = TI(I)                                                     ZULIA0040
```

69

```
34    GC TO 3                                                          ZULIA0049
      L = L + 1                                                        ZULIA0050
      NBAC(L) = 1                                                      ZULIA0051
3     CONTINUE                                                         ZULIA0052
                                                                       ZULIA0053
C     SPECIFY MATERIAL PROPERTIES: YOUNG'S MODULUS OF ELASTICITY XE, SHEAR  ZULIA0054
C     MODULUS OF ELASTICITY G, POISSON'S RATIO XNU.                    ZULIA0055
                                                                       ZULIA0056
C     IF THE MATHEMATICAL MODEL OF A PIPE IS USED, OUTPUTS ARGUMENTS OF ZULIA0057
C     SUBROUTINE CANTIL WILL DO IT.                                    ZULIA0058
                                                                       ZULIA0059
C     CALL    CANTIL(RG,RI,XE,G,XNU,SPECW,D,XL1,NPOINT,AREA,ALL1)      ZULIA0060
                                                                       ZULIA0061
                                                                       ZULIA0062
C     SPECIFY READINGS OF THE GAGE ELEMENTS, TO BE CONTAINED IN ARRAY  ZULIA0063
C     STRNEX.                                                          ZULIA0064
                                                                       ZULIA0065
C     THEORETICAL READINGS CAN BE OBTAINED FROM THE OUTPUT OF SUBROUTINE  ZULIA0066
C     TIUNA. THIS USES AS INFORMATION THE MATERIAL PROPERTIES AND ANGULAR  ZULIA0067
C     ORIENTATION OF EACH ELEMENT, AND THE STRESS COMPONENTS AT EACH   ZULIA0068
C     ELEMENT CENTER. THIS IS OBTAINED FROM THE OUTPUT ALL1 OF CANTIL, ZULIA0069
C     REQUIERING THE ANGULAR POSITION IN THE CROSS SECTION AND THE CROSS  ZULIA0070
C     SECTION NUMBER TO IDENTIFY THE RIGHT STRESSES.                   ZULIA0071
                                                                       ZULIA0072
      NSECT = 1                                                        ZULIA0073
      CALL TIUNA(XE,G,XNU,NSECT,ALL1,K,T,P,ZZ,TRANSV)                  ZULIA0074
                                                                       ZULIA0075
C     RANDOM ERRORS CAN BE ADDED TO THE THEORETICAL READINGS OF THE    ZULIA0076
C     GAGES, THE OUTPUT ZZ OF TIUNA, BY USING SUBROUTINE BLANCA.       ZULIA0077
C     SPECIFY THE MULTIPLIER ALT TO OBTAIN (ALT)*(10%) MAXIMUN RANDOM  ZULIA0078
C     ERROR ADDED.                                                     ZULIA0079
                                                                       ZULIA0080
      ALT = 0.3                                                        ZULIA0081
      CALL BLANCA(STRNEX,ZZ,K,ALT)                                     ZULIA0082
                                                                       ZULIA0083
C     PRINT-OUT OF ALL THE INFORMATION OBTAINED UP TO NOW.             ZULIA0084
                                                                       ZULIA0085
                                                                       ZULIA0086
500   WRITE(6, 500)                                                    ZULIA0087
      FORMAT(1H1)                                                      ZULIA0088
      WRITE(6,11)  NCOEFF                                              ZULIA0089
11    FORMAT(7(/),15X,'EXPANSION WITH',I3,' FOURIER COEFFICIENTS'//)   ZULIA0090
```

70

```fortran
      WRITE(6,30) XE,G,XNU,NGAGES,TRANSL,K
   30 FORMAT(15X,'MODULUS OF ELASTICITY',E13.5,' PSI'/
     1    15X,'SHEAR MODULUS OF ELASTICITY',E13.5,' PSI'//
     2    15X,'POISSON RATIO OF GAGES',E...,I4/
     3    15X,'NUMBER OF GAGES',I4/
     4    15X,'TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = ',F6.2,' %'/
     5    15X,'NUMBER OF GAGES FUNCTIONING PROPERLY',I4/)
   72 IF(...) GO TO 71
      WRITE(6,73)(NBAD(I),I=1,L)
   73 FORMAT(3X,8(I3,','))
      GO TO 71
   71 WRITE(6,74)
   74 FORMAT(6,...'GAGES FUNCTIONING IMPROPERLY',3X,8(I3,','))
   82 WRITE(6,83)
   83 FORMAT(15X,'GAGES FUNCTIONING IMPROPERLY ... NONE')
      WRITE(6,84)(T(N),N=1,K)
   84 FORMAT(/15X,'ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION,
     1    READ ROW WISE'//15X,6E15.5)
      WRITE(6,...)(X(N),N=1,K)
      FORMAT(/15X,'ANGULAR ORIENTATION OF THE GAGE ELEMENTS, READ ROW WISE'//
     1    15X,6E15.5)
      WRITE(6,85)(STRNEX(N),N=1,K)
   85 FORMAT(/15X,'READINGS OF THE GAGES, READ ROW WISE'//
     1    15X,6E15.5)
C
C     DETERMINATION OF THE FOURIER COEFFICIENTS. SUBROUTINE GUAYRA WILL
C     APPLY THE MATHEMATICAL METHOD FOR THIS. THE NUMBER J = NCOEFF*3
C     = TOTAL NUMBER OF COEFFICIENTS TO BE DETERMINED, IS NEEDED FOR
C     DIMENSIONING ARRAYS R AND W. NSECT AND AIL1 CAN BE USED FOR COMPAR-
C     ISONS BETWEEN THE ESTIMATED STRESS DISTRIBUTIONS AND THE THEORETICAL
C     ONES TAKEN FROM CANTIL.
C
      J = 3*NCOEFF
      CALL GUAYRA(NCOEFF,K,T,P,STRNEX,XE,G,XNU,J,R,W,NSECT,AIL1,TRANSV)
      RETURN
      END
```

```
      SUBROUTINE GUAYRA(RCOEFF,NGAGES,THETA,PHI,STRNEX,XE,G,XNU,
     1 JJ,P,W,NSECT,ALLI,TRANSV)
C
C     DETERMINES FOURIER COEFFICIENTS FOR THE DISTRIBUTIONS OF TANGENTIAL,
C     LONGITUDINAL AND SHEAR STRESSES. ALL ARGUMENTS ARE INPUTS.
C
C     NCOEFF = NUMBER OF FOURIER COEFFICIENTS FOR EACH STRESS DISTRIBUT-
C              ION.
C     NGAGES = NUMBER OF ACTIVE GAGE ELEMENTS.
C     THETA = ARRAY CONTAINING THE ANGULAR POSITION OF THE ELEMENTS
C             AROUND THE CROSS SECTION.
C     PHI = ARRAY CONTAINING THE ANGULAR ORIENTATION WITH RESPECT TO THE
C           TANGENTIAL AXIS OF THE ELEMENTS.
C     STRNEX = ARRAY CONTAINING THE READINGS OF THE ELEMENTS.
C     XE = YOUNG'S MODULUS OF ELASTICITY.
C     G = SHEAR MODULUS OF ELASTICITY.
C     XNU = POISSON'S RATIO.
C     JJ = 3*NCOEFF = TOTAL NUMBER OF COEFFICIENTS TO BE DETERMINED.
C     NSECT = SPECIFIED IN CALLING PROGRAM TO DIMENSION R AND W.
C     AND ALLI CAN BE USED TO COMPARE THE ESTIMATED STRESS DIS-
C     TRIBUTIONS AND THE THEORETICAL ONES FROM SUBPROGRAM CANTIL.
C
      DIMENSION THETA(36), PHI(36), ALLI(3,36,5),STRNEX(36), A(36),
     1 B(36), C(36),F(36,36), ST(36),SL(360),SH(360),STA(10),
     2 STR(10),SLA(10),SLP(10),SHA(10),SHB(10)
      DIMENSION R(JJ,JJ),W(JJ)
C
C     DETERMINE COEFFICIENTS A, B AND C.
C
      CALL GUMANA(XE, G, XNU,NGAGES,PHI,A, B, C, TRANSV)
      WRITE(6,88)
   88 FORMAT( 1H1 )
      WRITE(6,33)      ( A(N),N=1, NGAGES )
   33 FORMAT(7(/),15X,.COEFFICIENTS A. READ ROW WISE.//(15X,6E15.5))
      WRITE(6, 34)      ( B(N),N=1, NGAGES )
   34 FORMAT(6,/35)     ( C(N),N=1, NGAGES )
      WRITE(6, 35)      ( C(N),N=1, NGAGES )
   35 FORMAT(//15X,.COEFFICIENTS C, READ ROW WISE.//(15X,6E15.5))
C
C     FORM A SET OF SIMULTANEOUS EQUATIONS TO SOLVE FOR NSMLX5 FOURIER COEF-
C     FICIENTS. IN MATRIX NOTATION: (F)X(COEFF.S) = (H).
```

72

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GUAYR0050
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GUAYR0054
GUAYR0055
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GUAYR0057
GUAYR0058
GUAYR0059
GUAYR0060
GUAYR0061
GUAYR0062
GUAYR0063
GUAYR0064
GUAYR0065
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GUAYR0067
GUAYR0068
GUAYR0069
GUAYR0070
GUAYR0071
GUAYR0072
GUAYR0073
GUAYR0074
GUAYR0075
GUAYR0076
GUAYR0077
GUAYR0078
GUAYR0079
GUAYR0080
GUAYR0081
GUAYR0082
GUAYR0083
GUAYR0084
GUAYR0085
GUAYR0086
GUAYR0087
GUAYR0088
GUAYR0089
GUAYR0090
GUAYR0091
GUAYR0092
GUAYR0093
GUAYR0094
GUAYR0095
```

C

C
C   DETERMINE CONSTANTS H'S.
C

C
C   DETERMINE COEFFICIENTS F'S.
C

73

```
      BB = B(I)*B(I)
      BC = B(I)*C(I)
      CC = C(I)*C(I)
      PI2 = THETA(I)*PI2
      C1 = COS(AK*PI1)
      C2 = COS(AK*PI1)
      S1 = SIN(AK*PI1)
      S2 = SIN(AK*PI1)
      FF(LL,L+1) = FF(LL,M+1) = F(LL,M+1)*COS(AJ*PI1) + AA*C1
      FF(LL,L+1) = FF(LL,M+1) = F(LL,M+2)*SIN(AJ*PI1) + AA*C2
      FF(LL,L+1) = FF(LL,M+1) = F(LL,M+3)*COS(AJ*PI1) + AB*C1
      FF(LL,L+1) = FF(LL,M+1) = F(LL,M+4)*SIN(AJ*PI1) + AC*C2
      FF(LL,L+1) = FF(LL,M+1) = F(LL,M+5)*SIN(AJ*PI1) + AC*C1
      FF(LL,L+1) = FF(LL,M+1) = F(LL,M+1)*COS(AJ*PI1) + AC*C2
      FF(LL,L+2) = FF(LL,M+2) = F(LL,M+2)*SIN(AJ*PI1) + AA*S1
      FF(LL,L+2) = FF(LL,M+2) = F(LL,M+3)*COS(AJ*PI1) + AA*S2
      FF(LL,L+2) = FF(LL,M+2) = F(LL,M+4)*SIN(AJ*PI1) + AB*S1
      FF(LL,L+2) = FF(LL,M+2) = F(LL,M+5)*SIN(AJ*PI1) + AC*S2
      FF(LL,L+2) = FF(LL,M+2) = F(LL,M+1)*COS(AJ*PI1) + AB*S1
      FF(LL,L+3) = FF(LL,M+3) = F(LL,M+2)*SIN(AJ*PI1) + AB*S2
      FF(LL,L+3) = FF(LL,M+3) = F(LL,M+3)*COS(AJ*PI1) + BB*C2
      FF(LL,L+3) = FF(LL,M+3) = F(LL,M+4)*SIN(AJ*PI1) + BC*C1
      FF(LL,L+3) = FF(LL,M+3) = F(LL,M+5)*SIN(AJ*PI1) + BC*C2
      FF(LL,L+3) = FF(LL,M+3) = F(LL,M+1)*COS(AJ*PI1) + AB*S1
      FF(LL,L+4) = FF(LL,M+4) = F(LL,M+2)*SIN(AJ*PI1) + BB*S2
      FF(LL,L+4) = FF(LL,M+4) = F(LL,M+3)*COS(AJ*PI1) + BB*S1
      FF(LL,L+4) = FF(LL,M+4) = F(LL,M+4)*SIN(AJ*PI1) + BC*S2
      FF(LL,L+4) = FF(LL,M+4) = F(LL,M+5)*SIN(AJ*PI1) + AC*C1
      FF(LL,L+4) = FF(LL,M+4) = F(LL,M+1)*COS(AJ*PI1) + AC*C2
      FF(LL,L+5) = FF(LL,M+5) = F(LL,M+2)*SIN(AJ*PI1) + BC*C1
      FF(LL,L+5) = FF(LL,M+5) = F(LL,M+3)*COS(AJ*PI1) + BC*C2
      FF(LL,L+5) = FF(LL,M+5) = F(LL,M+4)*SIN(AJ*PI1) + CC*C2
      FF(LL,L+5) = FF(LL,M+5) = F(LL,M+5)*SIN(AJ*PI1) + AC*S2
      FF(LL,L+5) = FF(LL,M+5) = F(LL,M+1)*COS(AJ*PI1) + AC*S1
                                                      + BC*S1
                                                      + BC*S2
                                                      + CC*S1
                                                      + CC*S2
    2 CONTINUE
C
C     ELIMINATE ROWS AND COLUMNS OF ALL-ZERO ELEMENTS IN MATRIX F, COR-
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GUAYR096
GUAYR097
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GUAYR140
GUAYR141
GUAYR142
GUAYR143

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C     RESPONDING TO THE FOURIER COEFFICIENTS OF THE TERMS CONTAINING          GUAYR144
C     SIN(O), SO TO FORM A NONSINGULAR SET OF EQUATIONS. ELIMINATE COR-        GUAYR145
C     RESPONDING ELEMENTS IN CONSTANT MATRIX H. THE MATRIX EQUATION IS         GUAYR146
C     CONVERTED THEN TO (R)X(COEFF'S) = (W).                                   GUAYR147
                                                                               GUAYR148
      W(1) = H(1)                                                              GUAYR149
      R(1,1) = F(1,1)                                                          GUAYR150
      W(2) = H(3)                                                              GUAYR151
      R(1,2) = F(1,3)                                                          GUAYR152
      W(3) = H(5)                                                              GUAYR153
      R(1,3) = F(1,5)                                                          GUAYR154
      R(2,1) = F(3,1)                                                          GUAYR155
      R(2,2) = F(3,3)                                                          GUAYR156
      R(2,3) = F(3,5)                                                          GUAYR157
      R(3,1) = F(5,1)                                                          GUAYR158
      R(3,2) = F(5,3)                                                          GUAYR159
      R(3,3) = F(5,5)                                                          GUAYR160
      M = JJ                                                                    GUAYR161
      L = M+3                                                                   GUAYR162
      R(1,M) = H(M+3)                                                          GUAYR163
      R(1,M) = F(1,M+3)                                                        GUAYR164
      F(2,M) = F(3,M+3)                                                        GUAYR165
      R(3,M) = F(5,M+3)                                                        GUAYR166
      DO 50 M = 1,3                                                            GUAYR167
   50 R(M,L) = R(L,M)                                                          GUAYR168
      DO 51 M = 4,JJ                                                           GUAYR169
   51 R(L,M) = F(L+3, M+3)                                                     GUAYR170
                                                                               GUAYR171
C     SOLVE THE SET OF SIMULTANEOUS EQUATIONS TO DETERMINE JJ FOURIER          GUAYR172
C     COEFFICIENTS.                                                            GUAYR173
                                                                               GUAYR174
      CALL DSIMQ(R,W,JJ,KS)                                                    GUAYR175
      WRITE(6,38) NCOEFF                                                       GUAYR176
      WRITE(6,12)                                                              GUAYR177
   12 FORMAT(7(/),15X,'EXPANSION WITH',I3,' FOURIER COEFFICIENTS')            GUAYR178
      WRITE(6,100) KS                                                          GUAYR179
  100 FORMAT(//,15X,'KS =',I2,' KS IS AN INDEX INDICATING TYPE ',             GUAYR180
     1 'OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR')                           GUAYR181
                                                                               GUAYR182
C     GROUP THE FOURIER COEFFICIENTS FOR THE TANGENTIAL STRESS IN THE          GUAYR183
C     ARRAY STA, CORRESPONDING TO THE TERM CONTAINIG COS(N THETA), AND IN      GUAYR184
C     THE ARRAY STB CORRESPONDING FOR THE TERMS IN SIN(N THETA), FOR           GUAYR185
C     N = 1,2,...,(NCOEFF/2 + 1).                                              GUAYR186
C     SAME FOR LONGITUDINAL STRESS WITH SLA AND SLB, AND FOR SHEAR STRESS      GUAYR187
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75

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C     WITH SHA AND SHB.
      STA(1) = W(1)
      SLA(1) = W(2)
      SHA(1) = W(3)
      STB(1) = W(....)
      SHB(1) = W(....)
      DO 8  K = 2, NSML
      STA(2) = W(K+1)
      STB(2) = W(K+2)
      SLB(2) = W(K+3)
      SHA(2) = W(K+4)
      SHB(2) = W(K+5)
      K = K + 6
    8 CONTINUE
C
C     PREPARE ORDERLY PRINT-OUT OF THE FOURIER COEFFICIENTS.
C
   20 WRITE(6,20)  STA(1), SLA(1), SHA(1)
    1 FORMAT(//15X,'FOURIER COEFFICIENTS'//15X,8X,'CONSTANTS'/
     115X,'TANG.',E14.5,'LONG.',E14.5/15X,8X,'SHEAR',F14.5 )
      IF(NCOEFF .LT. 3 )  GO TO 3000
      IF(NCOEFF .EQ. 3 )  GO TO 3000
      IF(NCOEFF .EQ. 5 )  GO TO 5000
      IF(NCOEFF .EQ. 7 )  GO TO 7000
      IF(NCOEFF .EQ. 11 ) GO TO 9950
 3000 M = 1
      KS = 1
      I = 1
      LA = 2
      WRITE(6,3001) (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),
     1(SLA(N),SLB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)
 3001 FORMAT(//20X,'TANG.',2X,'COS.',I2,'(THETA),2X,'SIN.',I2,'(THETA), /
     115X,'LONG.',2E14.5/15X,'SHEAR',2E14.5 // )
      GO TO 600
 5000 M = 1
      KS = 2
      I = 1
      LA = 3
      WRITE(6,5001) (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),
     1(SLA(N),SLB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)
```

```
5001  FORMAT(//20X,2(2X,'COS',I2,'(THETA)',2X,'SIN',I2,'(THETA)')/
     1 15X,'TANG.',4F14.5/15X,'LONG.',4F14.5/15X,'SHEAR',4F14.5 //)
7000  M = 1
      KS = 2
      I = 4
      LA = 4
      WRITE(6,7001) (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),
     1 (SLA(N),SLB(N),N=I,LA)
7001  FORMAT(//20X,3(2X,'COS',I2,'(THETA)',2X,'SIN',I2,'(THETA)')/
     1 15X,'TANG.',6E14.5/15X,'LONG.',6E14.5/15X,'SHEAR',6E14.5 //)
9000  M = 1
      KS = 3
      I = 2
      LA = 4
      WRITE(6,7001) (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),
     1 (SLA(N),SLB(N),N=I,LA)
      M = 4
      KS = 4
      LA = 5
      WRITE(6,3001) (K,K, K = M,KS), (STA(N), STB(N), N=I,LA),
     1 (SLA(N),SLB(N),N=I,LA)
      GO TO 600
9050  M = 1
      KS = 3
      I = 2
      LA = 4
      WRITE(6,7001) (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),
     1 (SLA(N),SLB(N),N=I,LA)
      M = 4
      KS = 5
      LA = 6
      WRITE(6,5001) (K,K, K = M,KS), (STA(N), STB(N), N=I,LA),
     1 (SLA(N),SLB(N),N=I,LA)
600   CONTINUE
C
CC
CCC   COMPUTE RESULTANT STRESS COMPONENTS EVERY 10 DEGREES AROUND THE
CCCC  CROSS SECTION.
CCCCC
      DO 5  I = 1, 36
      ST(I) = 0.0.0
      SL(I) = 0.0.0
5     SH(I) = 0.0.0
```

GUAYR240
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GUAYR287

77

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C
      PI3 = 18.*PI2
      DO 6 I = 1, 36
      AI = I
      PI = AI*PI3
      DO 6 N = 1, NSML
      AN = N - 1
      C1 = COS( AN*PI )
      S1 = SIN( AN*PI )
      ST(II) = ST(II) + STA(N)*C1 + ST3(N)*S1
      SL(II) = SL(II) + SLA(N)*C1 + SL3(N)*S1
      SH(II) = SH(II) + SHA(N)*C1 + SH3(N)*S1
    6

C
C     PREPARE PRINT-OUT OF THE COMPUTED STRESSES AND THE CORRESPONDING
C     THEORETICAL ONES CONTAINED IN ALL1, IDENTIFIED BY THE NUMBER OF
C     THE CROSS SECTION NSECT.
C

      K = 1
      WRITE(6, 38)
      DO 7 N = 1, 36
      L = 10*(N-1)
      J = L + 1
      IF( K .LT. 13 )  GO TO 956
      K = 1
  954 WRITE(6, 88)
  956 WRITE(6, 11) L, J, (ALL1(I,J,NSECT), I = 1,3), ST(N), SL(N), SH(N)
   11 FORMAT(//15X, 'THETA =',I4,' DEGREES.', 5X,'POINT NO:', I4,  /
     1 15X,'STRESSES',9X,'TANG.',12X,'LONG.',12X,'SHEAR:', /
     2 15X,'ACTUAL ',3E17.5/15X,'COMPUTED',3E17.5)
    7 K = K + 1
      RETURN
      END
```

```
      SUBROUTINE CUMANA( E, G, V, NPOINT, P, A, B, C, AK)                CUMANO001
C                                                                       CUMANO002
C  TO COMPUTE COEFFICIENTS A, B AND C TO BE USED IN PROGRAM GUAYRA.      CUMANO003
C                                                                       CUMANO004
      DIMENSION F(36), A(36), B(36), C(36)                              CUMANO005
      PI2 = 3.141592655/180.0                                          CUMANO006
      DO 4 I=1,NPOINT                                                   CUMANO007
      PI = P(N)*PI2                                                     CUMANO008
      A(N) = (((1.0-C-AK*V)-(1.0-AK)*(1.0+V)*SIN(PI)**2)/(E*(1.0-AK**2)))CUMANO009
      B(N) = (((1.0-C-AK*V)-(1.0-AK)*(1.0+V)*COS(PI)**2)/(E*(1.0-AK**2)))CUMANO010
      C(N) = ((1.0-C-AK)*SIN(2.0*PI))/(2.0*G*(1.0-AK**2))               CUMANO011
    4 RETURN                                                            CUMANO012
      END                                                               CUMANO013
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79

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      SUBROUTINE TIUNA(E,G,V,K,AL,NBIG,T,P,S,AK)                    TIUNA001
C                                                                  TIUNA002
C  TO COMPUTE THE THEORETICAL READINGS OF A SET OF NBIG STRAIN GAGE TIUNA003
C  ELEMENTS WITH TRANSVERSE SENSITIVITY AK.                         TIUNA004
C                                                                  TIUNA005
C  ANGULAR POSITIONS OF THE ELEMENTS ARE CONTAINED IN THE ARRAY OF  TIUNA006
C  ANGLES T.                                                        TIUNA007
C  ANGULAR ORIENTATION OF THE ELEMENTS WITH RESPECT TO THE TANGENTIAL TIUNA008
C  AXIS ARE CONTAINED IN THE ARRAY OF ANGLES P.                     TIUNA009
C  COMPONENTS OF THE STRESSES AT EACH POSITION ARE CONTAINED IN THE  TIUNA010
C  ARRAY AL.  Y  IS THE NUMBER OF THE CROSS SECTION TO IDENTIFY THE  TIUNA011
C  CORRECT STRESSES.                                                TIUNA012
C  E IS YOUNG'S MODULUS OF ELASTICITY.                              TIUNA013
C  G IS THE SHEAR MODULUS OF ELASTICITY.                            TIUNA014
C  V IS POISSON'S RATIO.                                            TIUNA015
C  S IS THE OUTPUT SET OF READINGS.                                 TIUNA016
C                                                                  TIUNA017
      DIMENSION AL(3,360,5),T(36), P(36), S(36)                    TIUNA018
      PI2 = 3.14159265/180.C                                       TIUNA019
      DO 4  N=1,NBIG                                               TIUNA020
      J = T(N) + PI2                                               TIUNA021
      PI1 = P(N)*PI2                                               TIUNA022
      S1 = AL(1,J,K)                                               TIUNA023
      S2 = AL(2,J,K)                                               TIUNA024
      SS = AL(3,J,K)                                               TIUNA025
      A = ((1.0-AK)*(1.0+V))*SIN(PI1)**2)/(E*(1.0-AK**2))          TIUNA026
      B = ((1.0-AK)*(1.0+V))*COS(PI1)**2)/(E*(1.0-AK**2))          TIUNA027
      C = ((1.0-AK)*SIN(2.0*PI1))/(2.0*G*(1.0-AK**2))              TIUNA028
      S(N) = A*S1 + B*S2 + C*S3                                    TIUNA029
    4 CONTINUE                                                     TIUNA030
      RETURN                                                       TIUNA031
      END                                                          TIUNA032
```

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      SUBROUTINE BLANCA( CO, BE, N, ALT )                               BLANC0001
C                                                                       BLANC0003
C     INTRODUCES RANDOM ERRORS IN THE ELEMENTS OF ONE DIMENSIONAL ARRAY.BLANC0004
C     CO IS THE ARRAY INPUT AND BE IS THE OUTPUT.                       BLANC0005
C     N IS THE NUMBER OF ELEMENTS.                                      BLANC0006
C     ALT IS A MULTIPLIER TO PRODUCE PLUS OR MINUS (ALT)*(10%) MAXIMUN  BLANC0007
C     ERROR.                                                            BLANC0008
C                                                                       BLANC0009
      DIMENSION CO(36), BE(36)                                          BLANC0010
      RHO = 1, A                                                        BLANC0011
      DO 5 J = 1, A                                                     BLANC0012
      RHO = RHO + 3.6227                                                BLANC0013
      IF ( RHO - 5.995 ) 12, 11, 11                                     BLANC0014
   11 RHO = RHO - 8.4163                                                BLANC0015
   12 XX = RHO*( G/16.0 + 3.1416 )                                      BLANC0016
      XX = XX - AKX                                                     BLANC0017
      AKX = XX                                                         BLANC0018
      BKX = 10.0*BKX                                                   BLANC0019
      CKY = BE(J) - .01*ALT                                           BLANC0020
      TT = PERC = .01*CKX*TT                                          BLANC0021
      GQ = CKX*TT                                                     BLANC0022
      CKKX = XXXXX                                                    BLANC0023
      DKKKX = XXXXX                                                   BLANC0024
      GKKXX = DKKKX/2.0                                               BLANC0025
      FKKX = XXXXX                                                    BLANC0026
      LKKX = FKKX - GKKX                                              BLANC0027
      CKKX = XXXXX                                                    BLANC0028
      GKKX = FKKX - GKKX                                              BLANC0029
   15 IF(CKKX-0.5) 3, 1, 3                                            BLANC0030
    3 GO TO 5                                                        BLANC0031
    1 CO(J) = TT - GQ                                                BLANC0032
    5 CONTINUE                                                       BLANC0033
      PERC = PERC*1000.0                                             BLANC0034
      WRITE(6, 60) PERC                                              BLANC0035
   60 FORMAT(1H1//15X, 'MAXIMUN ERROR INTRODUCED', F6.1, '%', //     BLANC0036
      1 15X, 'ALTERATION OF THE STRAIN GAGE READINGS'//               BLANC0037
      2 7X, 'ALTERED', 34X, 'ORIGINAL',                              BLANC0038
      WRITE(6, 63) ( BE(J), CO(J), J = 1, N )                        BLANC0039
   63 FORMAT( 26X, 2E15.5 )                                          BLANC0040
      RETURN                                                        BLANC0041
      END                                                           BLANC0043
```

81

MODULUS CF ELASTICITY C.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.30000E 00

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 0 %
NUMBER OF GAGES FUNCTIONING PROPERLY 36
GAGES FUNCTIONING IMPROPERLY ... NONE

ANGULAR POSITION CF THE GAGE IN THE CROSS SECTION, READ ROW WISE

```
0.0           0.0           0.300000E 02   0.300000E 02
0.60000E 02   0.60000E 02   0.900000E 02   0.900000E 02
0.120000E 03  0.120000E 03  0.150000E 03   0.150000E 03
0.180000E 03  0.180000E 03  0.210000E 03   0.210000E 03
0.240000E 03  0.240000E 03  0.270000E 03   0.270000E 03
0.300000E 03  0.300000E 03  0.330000E 03   0.330000E 03
```

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

```
0.600000E 02   0.0      0.120000E 03   0.600000E 02   0.120000E 03
0.600000E 02   0.0      0.120000E 03   0.600000E 02   0.120000E 03
0.600000E 02   0.0      0.120000E 03   0.600000E 02   0.120000E 03
0.600000E 02   0.0      0.120000E 03   0.600000E 02   0.120000E 03
0.600000E 02   0.0      0.120000E 03   0.600000E 02   0.120000E 03
```

READINGS OF THE GAGE ELEMENTS, READ ROW WISE.   ERROR ADDED 0%

```
0.15134E-04   0.64178E-06   0.19479E-06   0.15127E-04   0.52988E-06   0.33917E-06
0.15118E-04   0.40066E-06   0.50589E-06   0.15111E-04   0.28876E-06   0.65028E-06
0.15107E-04   0.22415E-06   0.73364E-06   0.15107E-04   0.22415E-06   0.73364E-06
0.15111E-04   0.28876E-06   0.65028E-06   0.15118E-04   0.40066E-06   0.50589E-06
0.15127E-04   0.52988E-06   0.33917E-06   0.15134E-04   0.64178E-06   0.19479E-06
0.15138E-04   0.70639E-06   0.11143E-06   0.15138E-04   0.70639E-06   0.11143E-06
```

COEFFICIENTS A, READ ROW WISE

```
0.33333E-07   0.83336E-09   0.33333E-07   0.83336E-09   0.83333E-09
0.33333E-07   0.83336E-09   0.33333E-07   0.83336E-09   0.83333E-09
0.33333E-07   0.83336E-09   0.33333E-07   0.83336E-09   0.83333E-09
0.33333E-07   0.83336E-09   0.33333E-07   0.83336E-09   0.83333E-09
-0.33333E-07  0.83336E-09  -0.33333E-07   0.83336E-09   0.83333E-09
-0.33333E-07  0.83336E-09  -0.33333E-07   0.83336E-09  -0.83333E-11
```

COEFFICIENTS B, READ ROW WISE

```
-0.10000E-07  0.22500E-07  -0.10000E-07   0.22500E-07   0.22500E-07
-0.10000E-07  0.22500E-07  -0.10000E-07   0.22500E-07   0.22500E-07
-0.10000E-07  0.22500E-07  -0.10000E-07   0.22500E-07   0.22500E-07
-0.10000E-07  0.22500E-07  -0.10000E-07   0.22500E-07   0.22500E-07
-0.10000E-07  0.22500E-07  -0.10000E-07   0.22500E-07   0.22500E-07
-0.10000E-07  0.22500E-07  -0.10000E-07   0.22500E-07   0.22500E-07
```

COEFFICIENTS C, READ ROW WISE

```
0.37528E-07  -0.37528E-07   0.37528E-07   0.37528E-07  -0.37528E-07
0.37528E-07  -0.37528E-07   0.37528E-07   0.37528E-07  -0.37528E-07
0.37528E-07  -0.37528E-07   0.37528E-07   0.37528E-07  -0.37528E-07
0.37528E-07  -0.37528E-07   0.37528E-07   0.37528E-07  -0.37528E-07
0.0           0.0           0.0           0.0          -0.0
```

83

EXPANSION WITH 11 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

Note: If the system of equations for the
Fourier coefficients is singluar, this
fact is signaled by KS = 1. Any output
which follows is invalid.

```
            CONSTANTS
TANG.      0.45455E C3
LONG.      0.28943E C1
SHEAR      0.56926E CC
```

```
            COS 1(THETA)    SIN 1(THETA)    COS 2(THETA)    SIN 2(THETA)    COS 3(THETA)    SIN 3(THETA)
TANG.      -0.51868E-03    -0.95258E-04     0.16030E-04    -0.52048E-04     0.94102E-05    -0.21859E-04
LONG.      -0.11386E 01    -0.11385E 01    -0.83788E-04    -0.39759E-04    -0.68131E-04    -0.23244E-04
SHEAR       0.53861E 01    -0.53860E 01     0.82367E-05     0.46219E-05    -0.20428E-05    -0.13867E-05
```

```
            COS 4(THETA)    SIN 4(THETA)    COS 5(THETA)    SIN 5(THETA)
TANG.       0.38785E-04    -0.16227E-05    -0.13316E-05     0.42612E-04
LONG.      -0.59643E-04    -0.35988E-04     0.16735E-06     0.61955E-06
SHEAR       0.56175E-06    -0.41939E-06     0.42750E-06    -0.26063E-06
```

84

```
THETA =    0 DEGREES        POINT NO.    1
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.17552E 01         0.59553E 01
COMPUTED        0.45455E 03         0.17554E 01         0.59553E 01


THETA =   10 DEGREES        POINT NO.   11
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.19702E 01         0.49382E 01
COMPUTED        0.45455E 03         0.19704E 01         0.49382E 01


THETA =   20 DEGREES        POINT NO.   21
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.22133E 01         0.37884E 01
COMPUTED        0.45455E 03         0.22135E 01         0.37884E 01


THETA =   30 DEGREES        POINT NO.   31
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.24770E 01         0.25407E 01
COMPUTED        0.45454E 03         0.24773E 01         0.25407E 01


THETA =   40 DEGREES        POINT NO.   41
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.27534E 01         0.12331E 01
COMPUTED        0.45454E 03         0.27538E 01         0.12331E 01


THETA =   50 DEGREES        POINT NO.   51
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.30341E 01        -0.94609E-01
COMPUTED        0.45454E 03         0.30345E 01        -0.94599E-01


THETA =   60 DEGREES        POINT NO.   61
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.33104E 01        -0.14022E 01
COMPUTED        0.45455E 03         0.33110E 01        -0.14022E 01


THETA =   70 DEGREES        POINT NO.   71
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.35742E 01        -0.26498E 01
COMPUTED        0.45455E 03         0.35748E 01        -0.26498E 01


THETA =   80 DEGREES        POINT NO.   81
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.38172E 01        -0.37997E 01
COMPUTED        0.45455E 03         0.38178E 01        -0.37997E 01


THETA =   90 DEGREES        POINT NO.   91
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.40322E 01        -0.48168E 01
COMPUTED        0.45455E 03         0.40328E 01        -0.48168E 01


THETA =  100 DEGREES        POINT NO.  101
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.42126E 01        -0.56702E 01
COMPUTED        0.45455E 03         0.42132E 01        -0.56702E 01


THETA =  110 DEGREES        POINT NO.  111
STRESSES          TANG.               LONG.                SHEAR
ACTUAL          0.45455E 03         0.43530E 01        -0.63341E 01
COMPUTED        0.45455E 03         0.43535E 01        -0.63341E 01
```

```
THETA = 120 DEGREES      POINT NO. 121
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.44490E 01      -0.67882E 01
COMPUTED         0.45455E 03       0.44495E 01      -0.67882E 01


THETA = 130 DEGREES      POINT NO. 131
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.44977E 01      -0.70188E 01
COMPUTED         0.45455E 03       0.44982E 01      -0.70188E 01


THETA = 140 DEGREES      POINT NO. 141
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.44977E 01      -0.70188E 01
COMPUTED         0.45455E 03       0.44983E 01      -0.70188E 01


THETA = 150 DEGREES      POINT NO. 151
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.44490E 01      -0.67882E 01
COMPUTED         0.45455E 03       0.44496E 01      -0.67882E 01


THETA = 160 DEGREES      POINT NO. 161
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.43530E 01      -0.63341E 01
COMPUTED         0.45455E 03       0.43537E 01      -0.63341E 01


THETA = 170 DEGREES      POINT NO. 171
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.42126E 01      -0.56703E 01
COMPUTED         0.45455E 03       0.42133E 01      -0.56702E 01


THETA = 180 DEGREES      POINT NO. 181
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.40322E 01      -0.48168E 01
COMPUTED         0.45455E 03       0.40328E 01      -0.48168E 01


THETA = 190 DEGREES      POINT NO. 191
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.38172E 01      -0.37997E 01
COMPUTED         0.45455E 03       0.38178E 01      -0.37997E 01


THETA = 200 DEGREES      POINT NO. 201
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.35742E 01      -0.26498E 01
COMPUTED         0.45455E 03       0.35747E 01      -0.26498E 01


THETA = 210 DEGREES      POINT NO. 211
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.33105E 01      -0.14022E 01
COMPUTED         0.45455E 03       0.33110E 01      -0.14022E 01


THETA = 220 DEGREES      POINT NO. 221
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.30341E 01      -0.94623E-01
COMPUTED         0.45455E 03       0.30347E 01      -0.94618E-01


THETA = 230 DEGREES      POINT NO. 231
STRESSES          TANG.             LONG.             SHEAR
ACTUAL           0.45455E 03       0.27534E 01       0.12331E 01
COMPUTED         0.45455E 03       0.27541E 01       0.12331E 01
```

```
THETA = 240 DEGREES        POINT NO. 241
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.24770E 01        0.25407E 01
COMPUTED            0.45455E C3        0.24777E 01        0.25407E 01


THETA = 250 DEGREES        POINT NO. 251
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.22133E 01        0.37883E 01
COMPUTED            0.45455F C3        0.22139E 01        0.37883E 01


THETA = 260 DEGREES        POINT NO. 261
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.19702F 01        0.49382E 01
COMPUTED            0.45455E C3        0.19708E 01        0.49382E 01


THETA = 270 DEGREES        POINT NO. 271
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.17552E 01        0.59553E 01
COMPUTED            0.45455E C3        0.17558E 01        0.59553E 01


THETA = 280 DEGREES        POINT NO. 281
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.15748E 01        0.68088F 01
COMPUTED            0.45455E C3        0.15754E 01        0.68087E 01


THETA = 290 DEGREES        POINT NO. 291
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.14345E 01        0.74726E 01
COMPUTED            0.45455E C3        0.14351E 01        0.74726E 01


THETA = 300 DEGREES        POINT NO. 301
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.13385E 01        0.79267E 01
COMPUTED            0.45455E C3        0.13392E 01        0.79267E 01


THETA = 310 DEGREES        POINT NO. 311
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.12898E 01        0.81573F 01
COMPUTED            0.45455E C3        0.12905E 01        0.81573E 01


THETA = 320 DEGREES        POINT NO. 321
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.12897E 01        0.81573E 01
COMPUTED            0.45455E C3        0.12904E 01        0.81573E 01


THETA = 330 DEGREES        POINT NO. 331
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.13385E 01        0.79267E 01
COMPUTED            0.45455E C3        0.13390E 01        0.79267E 01


THETA = 340 DEGREES        POINT NO. 341
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.14345E 01        0.74726E 01
COMPUTED            0.45455E C3        0.14348E 01        0.74726E 01


THETA = 350 DEGREES        POINT NO. 351
STRESSES              TANG.              LONG.              SHEAR
ACTUAL              0.45455E C3        0.15748F 01        0.68088E 01
COMPUTED            0.45455E C3        0.15751E 01        0.68088E 01
```

EXPANSION WITH 3 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

CONSTANTS
TANG.   0.45455E 03
LONG.   0.28943E 01
SHEAR   0.56926E 00

         COS 1(THETA)   SIN 1(THETA)
TANG.   -0.51868E-03   -0.95258E-04
LONG.   -0.11386E 01   -0.11385E 01
SHEAR   0.53861E 01   -0.53860E 01

```
THETA =    0 DEGREES      POINT NO.    1
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.17552E 01        0.59553E 01
COMPUTED       0.45455E 03        0.17556E 01        0.59553E 01


THETA =   10 DEGREES      POINT NO.   11
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.19702E 01        0.49382E 01
COMPUTED       0.45455E 03        0.19706E 01        0.49382E 01


THETA =   20 DEGREES      POINT NO.   21
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.22133E 01        0.37884E 01
COMPUTED       0.45455E 03        0.22137E 01        0.37884E 01


THETA =   30 DEGREES      POINT NO.   31
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.24770E 01        0.25407E 01
COMPUTED       0.45455E 03        0.24774E 01        0.25407E 01


THETA =   40 DEGREES      POINT NO.   41
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.27534E 01        0.12331E 01
COMPUTED       0.45455E 03        0.27538E 01        0.12331E 01


THETA =   50 DEGREES      POINT NO.   51
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.30341E 01       -0.94609E-01
COMPUTED       0.45455E 03        0.30345E 01       -0.94604E-01


THETA =   60 DEGREES      POINT NO.   61
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.33104E 01       -0.14022E 01
COMPUTED       0.45455E 03        0.33109E 01       -0.14022E 01


THETA =   70 DEGREES      POINT NO.   71
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.35742E 01       -0.26498E 01
COMPUTED       0.45455E 03        0.35746E 01       -0.26498E 01


THETA =   80 DEGREES      POINT NO.   81
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.38172E 01       -0.37997E 01
COMPUTED       0.45455E 03        0.38177E 01       -0.37997E 01


THETA =   90 DEGREES      POINT NO.   91
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.40322E 01       -0.48168E 01
COMPUTED       0.45455E 03        0.40327E 01       -0.48168E 01


THETA =  100 DEGREES      POINT NO.  101
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.42126E 01       -0.56702E 01
COMPUTED       0.45455E 03        0.42132E 01       -0.56702E 01


THETA =  110 DEGREES      POINT NO.  111
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03        0.43530E 01       -0.63341E 01
COMPUTED       0.45455E 03        0.43535E 01       -0.63341E 01
```

```
THETA = 120 DEGREES      POINT NO. 121
STRESSES          TANG.       .       LONG.                SHEAR
ACTUAL            0.45455E 03          0.44490E 01      -0.67882E 01
COMPUTED          0.45455E 03          0.44495E 01      -0.67882E 01


THETA = 130 DEGREES      POINT NO. 131
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.44977E 01      -0.70188E 01
COMPUTED          0.45455E 03          0.44983E 01      -0.70188E 01


THETA = 140 DEGREES      POINT NO. 141
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.44977E 01      -0.70188E 01
COMPUTED          0.45455E 03          0.44983E 01      -0.70188E 01


THETA = 150 DEGREES      POINT NO. 151
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.44490E 01      -0.67882E 01
COMPUTED          0.45455E 03          0.44496E 01      -0.67882E 01


THETA = 160 DEGREES      POINT NO. 161
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.43530E 01      -0.63341E 01
COMPUTED          0.45455E 03          0.43536E 01      -0.63341E 01


THETA = 170 DEGREES      POINT NO. 171
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.42126E 01      -0.56703E 01
COMPUTED          0.45455E 03          0.42133E 01      -0.56702E 01


THETA = 180 DEGREES      POINT NO. 181
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.40322E 01      -0.48168E 01
COMPUTED          0.45455E 03        . 0.40329E 01      -0.48168E 01


THETA = 190 DEGREES      POINT NO. 191
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.38172E 01      -0.37997E 01
COMPUTED          0.45455E 03          0.38179E 01      -0.37997E 01


THETA = 200 DEGREES      POINT NO. 201
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.35742E 01      -0.26498E 01
COMPUTED          0.45455E 03          0.35749E 01      -0.26498E 01


THETA = 210 DEGREES      POINT NO. 211
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.33105E 01      -0.14022E 01
COMPUTED          0.45455E 03          0.33111E 01      -0.14022E 01


THETA = 220 DEGREES      POINT NO. 221
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.30341E 01      -0.94623E-01
COMPUTED          0.45455E 03          0.30347E 01      -0.94625E-01


THETA = 230 DEGREES      POINT NO. 231
STRESSES          TANG.                LONG.                SHEAR
ACTUAL            0.45455E 03          0.27534E 01       0.12331E 01
COMPUTED          0.45455E 03          0.27541E 01       0.12331E 01
```

```
THETA = 240 DEGREES       POINT NO. 241
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.24770E 01            0.25407E 01
COMPUTED        0.45455E 03        0.24777E 01            0.25407E 01


THETA = 250 DEGREES       POINT NO. 251
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.22133E 01            0.37883E 01
COMPUTED        0.45455E 03        0.22139E 01            0.37883E 01


THETA = 260 DEGREES       POINT NO. 261
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.19702E 01            0.49382E 01
COMPUTED        0.45455E 03        0.19708E 01            0.49382E 01


THETA = 270 DEGREES       POINT NO. 271
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.17552E 01            0.59553E 01
COMPUTED        0.45455E 03        0.17558E 01            0.59553E 01


THETA = 280 DEGREES       POINT NO. 281
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.15748E 01            0.68088E 01
COMPUTED        0.45455E 03        0.15754E 01            0.68087E 01


THETA = 290 DEGREES       POINT NO. 291
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.14345E 01            0.74726E 01
COMPUTED        0.45455E 03        0.14350E 01            0.74726E 01


THETA = 300 DEGREES       POINT NO. 301
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.13385E 01            0.79267E 01
COMPUTED        0.45455E 03        0.13390E 01            0.79267E 01


THETA = 310 DEGREES       POINT NO. 311
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.12898E 01            0.81573E 01
COMPUTED        0.45455E 03        0.12903E 01            0.81573E 01


THETA = 320 DEGREES       POINT NO. 321
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.12897E 01            0.81573E 01
COMPUTED        0.45455E 03        0.12902E 01            0.81573E 01


THETA = 330 DEGREES       POINT NO. 331
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.13385E 01            0.79267E 01
COMPUTED        0.45455E 03        0.13390E 01            0.79267E 01


THETA = 340 DEGREES       POINT NO. 341
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.14345E 01            0.74726E 01
COMPUTED        0.45455E 03        0.14349E 01            0.74726E 01


THETA = 350 DEGREES       POINT NO. 351
STRESSES           TANG.              LONG.                    SHEAR
ACTUAL          0.45455E 03        0.15748E 01            0.68088E 01
COMPUTED        0.45455E 03        0.15752E 01            0.68088E 01
```

91

MODULUS OF ELASTICITY C.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.30000E 00

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 0 %
NUMBER OF GAGES FUNCTIONING PROPERLY 30
GAGES FUNCTIONING IMPROPERLY 2, 12, 22, 24, 25, 33,

ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION, READ ROW WISE

0.0	0.30000E 02	0.300000E 02	0.600000E 02
0.60000E 02	0.90000E 02	0.900000E 02	0.180000E 03
0.12000E 03	0.15000E 03	0.180000E 03	0.270000E 03
0.18000E 03	0.21000E 03	0.240000E 03	0.330000E 03
0.27000E 03	0.30000E 03	0.300000E 03	

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

0.0	0.12000E 03	0.60000E 02	0.0
0.60000E 02	0.12000E 03	0.60000E 02	0.60000E 02
0.12000E 03	0.60000E 02	0.12000E 03	0.60000E 02
0.12000E 03	0.0	0.12000E 03	0.12000E 03
0.12000E 03	0.60000E 02	0.0	0.60000E 02

READINGS OF THE GAGE ELEMENTS, READ ROW WISE.   ERROR ADDED 0%

0.15134E-04	0.15127E-04	0.52988E-06	0.15118E-04
0.40066E-06	0.15111E-04	0.28876E-06	0.22415E-06
0.73364E-06	0.22415E-06	0.73364E-06	0.28876E-06
0.65028E-06	0.52988E-06	0.33917E-06	0.64178E-06
0.19479E-06	0.70639E-06	0.15138E-04	0.11143E-06

92

COEFFICIENTS A, READ ROW WISE

```
 0.33333E-07   0.83333E-09   0.33333E-07   0.33333E-07   0.33333E-07
-0.83336E-09   0.83333E-09   0.83336E-09   0.33333E-09   0.83336E-09
-0.83333E-09   0.83333E-09   0.83333E-09   0.83336E-09   0.83336E-09
 0.83333E-09   0.33333E-07   0.83333E-09   0.83336E-09   0.83333E-09
```

COEFFICIENTS B, READ ROW WISE

```
-0.10000E-07   0.22500E-07  -0.10000E-07  -0.10000E-07  -0.10000E-07
 0.22500E-07   0.10000E-07   0.22500E-07   0.22500E-07   0.22500E-07
 0.22500E-07  -0.10000E-07   0.22500E-07   0.22500E-07   0.22500E-07
 0.22500E-07  -0.10000E-07  -0.10000E-07   0.22500E-07   0.22500E-07
```

COEFFICIENTS C, READ ROW WISE

```
-0.37528E-07   0.37528E-07  -0.37528E-07  -0.37528E-07   0.0
-0.37528E-07   0.0          -0.37528E-07   0.0            0.37528E-07
-0.37528E-07   0.0           0.37528E-07   0.37528E-07    0.37528E-07
-0.37528E-07   0.0          -0.0           0.0           -0.37528E-07
```

EXPANSION WITH 3 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

          CONSTANTS
TANG.   0.45455E 03
LONG.   0.28943E 01
SHEAR   0.56921E 00

          COS 1(THETA)   SIN 1(THETA)
TANG.   -0.94754E-03   -0.57504E-03
LONG.   -0.11387E 01   -0.11384E 01
SHEAR   0.53861E 01   -0.53860E 01

94

```
THETA =    0 DEGREES        POINT NO.    1
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.17552E 01        0.59553E 01
COMPUTED       0.45454E 03       0.17556E 01        0.59553E 01


THETA =   10 DEGREES        POINT NO.   11
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.19702E 01        0.49382E 01
COMPUTED       0.45454E 03       0.19706E 01        0.49382E 01


THETA =   20 DEGREES        POINT NO.   21
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.22133E 01        0.37884E 01
COMPUTED       0.45454E 03       0.22136E 01        0.37884E 01


THETA =   30 DEGREES        POINT NO.   31
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.24770E 01        0.25407E 01
COMPUTED       0.45454E 03       0.24774E 01        0.25407E 01


THETA =   40 DEGREES        POINT NO.   41
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.27534E 01        0.12331E 01
COMPUTED       0.45454E 03       0.27538E 01        0.12331E 01


THETA =   50 DEGREES        POINT NO.   51
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.30341E 01       -0.94609E-01
COMPUTED       0.45454E 03       0.30344E 01       -0.94596E-01


THETA =   60 DEGREES        POINT NO.   61
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.33104E 01       -0.14022E 01
COMPUTED       0.45454E 03       0.33108E 01       -0.14022E 01


THETA =   70 DEGREES        POINT NO.   71
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.35742E 01       -0.26498E 01
COMPUTED       0.45454E 03       0.35746E 01       -0.26498E 01


THETA =   80 DEGREES        POINT NO.   81
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.38172E 01       -0.37997E 01
COMPUTED       0.45454E 03       0.38177E 01       -0.37997E 01


THETA =   90 DEGREES        POINT NO.   91
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.40322E 01       -0.48168E 01
COMPUTED       0.45454E 03       0.40327E 01       -0.48168E 01


THETA =  100 DEGREES        POINT NO.  101
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.42126E 01       -0.56702E 01
COMPUTED       0.45454E 03       0.42131E 01       -0.56703E 01


THETA =  110 DEGREES        POINT NO.  111
STRESSES          TANG.              LONG.                  SHEAR
ACTUAL         0.45455E 03       0.43530E 01       -0.63341E 01
COMPUTED       0.45455E 03       0.43535E 01       -0.63341E 01
```

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MODULUS OF ELASTICITY 0.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.30000E 00

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 0 %
NUMBER OF GAGES FUNCTIONING PROPERLY 36
GAGES FUNCTIONING IMPROPERLY ... NONE
```

ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION, READ ROW WISE

```
0.0           0.60000E 02   0.30000E 02   0.30000E 02   0.30000E 02   0.30000E 02
0.60000E 02   0.12000E 03   0.90000E 02   0.90000E 02   0.90000E 02   0.90000E 02
0.12000E 03   0.18000E 03   0.15000E 03   0.15000E 03   0.15000E 03   0.15000E 03
0.18000E 03   0.24000E 03   0.21000E 03   0.21000E 03   0.21000E 03   0.21000E 03
0.24000E 03   0.30000E 03   0.27000E 03   0.27000E 03   0.27000E 03   0.27000E 03
0.30000E 03   0.30000E 03   0.33000E 03   0.33000E 03   0.33000E 03   0.33000E 03
```

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

```
0.60000E 02   0.0   0.12000E 03   0.60000E 02   0.60000E 02   0.12000E 03
0.60000E 02   0.0   0.12000E 03   0.60000E 02   0.60000E 02   0.12000E 03
0.60000E 02   0.0   0.12000E 03   0.60000E 02   0.60000E 02   0.12000E 03
0.60000E 02   0.0   0.12000E 03   0.60000E 02   0.60000E 02   0.12000E 03
0.60000E 02   0.0   0.12000E 03   0.60000E 02   0.60000E 02   0.12000E 03
0.60000E 02   0.0   0.12000E 03   0.60000E 02   0.60000E 02   0.12000E 03
```

READINGS OF THE GAGE ELEMENTS, READ ROW WISE. ERROR ADDED 2%

```
0.15134E-04   0.63164E-06   0.19596E-06   0.14907E-04   0.53904E-06   0.33688E-06
0.14833E-04   0.40585E-06   0.50206E-06   0.15126E-04   0.29224E-06   0.63844E-06
0.15008E-04   0.22446E-06   0.73175E-06   0.14883E-04   0.22505E-06   0.73152E-06
0.15183E-04   0.29368E-06   0.64296E-06   0.14880E-04   0.40417E-06   0.49667E-06
0.14843E-04   0.53846E-06   0.33419E-06   0.15091E-04   0.64980E-06   0.19406E-06
0.15088E-04   0.71787E-06   0.11202E-06   0.15327E-04   0.71808E-06   0.11338E-06
```

EXPANSION WITH 11 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

CONSTANTS
TANG.   0.45167E 03
LONG.   0.30279E 01
SHEAR   0.67538E 00

	COS 1(THETA)	SIN 1(THETA)	COS 2(THETA)	SIN 2(THETA)	COS 3(THETA)	SIN 3(THETA)
TANG.	0.16451E 01	-0.94166E 00	-0.10407E 01	-0.36258E 01	-0.60751E 00	-0.22247E 01
LONG.	-0.11111E 01	-0.10538E 01	-0.76545E-01	-0.86755E-01	-0.51607E-01	-0.13186E 00
SHEAR	0.53511E 01	-0.54097E 01	-0.47720E-01	0.44068E-01	-0.65953E-01	-0.32323E-01

	COS 4(THETA)	SIN 4(THETA)	COS 5(THETA)	SIN 5(THETA)
TANG.	0.31820E 01	-0.17485E-01	-0.21132E 01	0.46379E 00
LONG.	-0.21402E 00	-0.24257E-01	-0.92955E-02	0.12406E-01
SHEAR	-0.22891E-01	-0.17709E-03	-0.55914E-01	0.34983E-01

```
THETA = 240 DEGREES      POINT NO. 241
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.24770E 01        0.25407E 01
COMPUTED        0.44647E C3       0.28761E 01        0.27506E 01


THETA = 250 DEGREES      POINT NO. 251
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.22133E 01        0.37883E 01
COMPUTED        0.44979E C3       0.25514E 01        0.39775E 01


THETA = 260 DEGREES      POINT NO. 261
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.19702E 01        0.49382E 01
COMPUTED        0.45222E 03       0.22239E 01        0.50755E 01


THETA = 270 DEGREES      POINT NO. 271
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.17552E 01        0.59553E 01
COMPUTED        0.45299E 03       0.19561E 01        0.60426E 01


THETA = 280 DEGREES      POINT NO. 281
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.15748E 01        0.68088E 01
COMPUTED        0.45262E 03       0.17848E 01        0.68838E 01


THETA = 290 DEGREES      POINT NO. 291
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.14345E 01        0.74726E 01
COMPUTED        0.45243E C3       0.17031E 01        0.75850E 01


THETA = 300 DEGREES      POINT NO. 301
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.13385E 01        0.79267E 01
COMPUTED        0.45347E C3       0.16666E 01        0.81011E 01


THETA = 310 DEGREES      POINT NO. 311
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.12898E 01        0.81573E 01
COMPUTED        0.45576E C3       0.16207E 01        0.83706E 01


THETA = 320 DEGREES      POINT NO. 321
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.12897E 01        0.81573E 01
COMPUTED        0.45836E C3       0.15346E 01        0.83472E 01


THETA = 330 DEGREES      POINT NO. 331
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.13385E 01        0.79267E 01
COMPUTED        0.45993E C3       0.14234E 01        0.80272E 01


THETA = 340 DEGREES      POINT NO. 341
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.14345E 01        0.74726E 01
COMPUTED        0.45968E C3       0.13451E 01        0.74556E 01


THETA = 350 DEGREES      POINT NO. 351
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E C3       0.15748E 01        0.68088E 01
COMPUTED        0.45770E C3       0.13746E 01        0.67035E 01
```

EXPANSION WITH 5 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

CONSTANTS
TANG.   0.45167E 03
LONG.   0.30279E 01
SHEAR   0.67538E 00

	COS 1(THETA)	SIN 1(THETA)	COS 2(THETA)	SIN 2(THETA)
TANG.	-0.16451E 01	-0.94167E 00	-0.10407E 01	-0.36258E 01
LONG.	-0.11111E 01	-0.10538E 01	-0.76546E-01	0.86754E-01
SHEAR	0.53511E 01	-0.54097E 01	-0.47720E-01	0.44068E-01

```
THETA = 240 DEGREES      POINT NO. 241
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.24770E 01          0.25407E 01
COMPUTED        0.44800E 03      0.27843E 01          0.27467E 01


THETA = 250 DEGREES      POINT NO. 251
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.22133E 01          0.37883E 01
COMPUTED        0.44886E 03      0.25321E 01          0.39935E 01


THETA = 260 DEGREES      POINT NO. 261
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.19702E 01          0.49382E 01
COMPUTED        0.45009E 03      0.22847E 01          0.51336E 01


THETA = 270 DEGREES      POINT NO. 271
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.17552E 01          0.59553E 01
COMPUTED        0.45157E 03      0.20507E 01          0.61327E 01


THETA = 280 DEGREES      POINT NO. 281
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.15748E 01          0.68088E 01
COMPUTED        0.45314E 03      0.18395E 01          0.69618E 01


THETA = 290 DEGREES      POINT NO. 291
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.14345E 01          0.74726E 01
COMPUTED        0.45465E 03      0.16605E 01          0.75972E 01


THETA = 300 DEGREES      POINT NO. 301
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.13385E 01          0.79267E 01
COMPUTED        0.45592E 03      0.15229E 01          0.80215E 01


THETA = 310 DEGREES      POINT NO. 311
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.12898E 01          0.81573E 01
COMPUTED        0.45684E 03      0.14343E 01          0.82239E 01


THETA = 320 DEGREES      POINT NO. 321
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.12897E 01          0.81573E 01
COMPUTED        0.45728E 03      0.14007E 01          0.82001E 01


THETA = 330 DEGREES      POINT NO. 331
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.13385E 01          0.79267E 01
COMPUTED        0.45722E 03      0.14253E 01          0.79524E 01


THETA = 340 DEGREES      POINT NO. 341
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.14345E 01          0.74726E 01
COMPUTED        0.45666E 03      0.15090E 01          0.74891E 01


THETA = 350 DEGREES      POINT NO. 351
STRESSES          TANG.             LONG.                SHEAR
ACTUAL          0.45455E 03      0.15748E 01          0.68088E 01
COMPUTED        0.45567E 03      0.16491E 01          0.68246E 01
```

EXPANSION WITH 3 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

```
          CONSTANTS
TANG.     0.45167E 03
LONG.     0.30279E 01
SHEAR     0.67538E 00

          COS 1(THETA)    SIN 1(THETA)
TANG.     0.16451E 01    -0.94167E 00
LONG.    -0.11111E 01    -0.10533E 01
SHEAR    -0.53511E 01    -0.54097E 01
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```
THETA = 240 DEGREES      POINT NO. 241
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.24770E 01          0.25407E 01
COMPUTED           0.45166E 03        0.26709E 01          0.26847E 01


THETA = 250 DEGREES      POINT NO. 251
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.22133E 01          0.37883E 01
COMPUTED           0.45199E 03        0.24177E 01          0.39286E 01


THETA = 260 DEGREES      POINT NO. 261
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.19702E 01          0.49382E 01
COMPUTED           0.45231E 03        0.21831E 01          0.50736E 01


THETA = 270 DEGREES      POINT NO. 271
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.17552E 01          0.59553E 01
COMPUTED           0.45261E 03        0.19741E 01          0.60850E 01


THETA = 280 DEGREES      POINT NO. 281
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.15748E 01          0.68088E 01
COMPUTED           0.45288E 03        0.17972E 01          0.69321E 01


THETA = 290 DEGREES      POINT NO. 291
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.14345E 01          0.74726E 01
COMPUTED           0.45311E 03        0.16577E 01          0.75890E 01


THETA = 300 DEGREES      POINT NO. 301
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.13385E 01          0.79267E 01
COMPUTED           0.45330E 03        0.15597E 01          0.80358E 01


THETA = 310 DEGREES      POINT NO. 311
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.12898E 01          0.81573E 01
COMPUTED           0.45345E 03        0.15064E 01          0.82590E 01


THETA = 320 DEGREES      POINT NO. 321
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.12897E 01          0.81573E 01
COMPUTED           0.45353E 03        0.14994E 01          0.82518E 01


THETA = 330 DEGREES      POINT NO. 331
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.13385E 01          0.79267E 01
COMPUTED           0.45356E 03        0.15388E 01          0.80144E 01


THETA = 340 DEGREES      POINT NO. 341
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.14345E 01          0.74726E 01
COMPUTED           0.45353E 03        0.16234E 01          0.75540E 01


THETA = 350 DEGREES      POINT NO. 351
STRESSES            TANG.              LONG.                 SHEAR
ACTUAL             0.45455E 03        0.15748E 01          0.68088E 01
COMPUTED           0.45345E 03        0.17507E 01          0.68846E 01
```

MODULUS OF ELASTICITY 0.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.30000E 00

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 1 %
NUMBER OF GAGES FUNCTIONING PROPERLY 36
GAGES FUNCTIONING IMPROPERLY ... NONE

ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION, READ ROW WISE

0.0	0.0	0.30000E 02	0.30000E 02	0.30000E 02
0.60000E 02	0.60000E 02	0.90000E 02	0.90000E 02	0.90000E 02
0.12000E 03	0.12000E 03	0.15000E 03	0.15000E 03	0.15000E 03
0.18000E 03	0.18000E 03	0.21000E 03	0.21000E 03	0.21000E 03
0.24000E 03	0.24000E 03	0.27000E 03	0.27000E 03	0.27000E 03
0.30000E 03	0.30000E 03	0.33000E 03	0.33000E 03	0.33000E 03

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

0.0	0.0	0.60000E 02	0.60000E 02	0.12000E 03
0.60000E 02	0.60000E 02	0.60000E 02	0.60000E 02	0.12000E 03
0.0	0.0	0.60000E 02	0.60000E 02	0.12000E 03
0.0	0.0	0.60000E 02	0.60000E 02	0.12000E 03
0.0	0.0	0.60000E 02	0.60000E 02	0.12000E 03
0.0	0.0	0.60000E 02	0.60000E 02	0.12000E 03

READINGS OF THE GAGE ELEMENTS, READ ROW WISE. ERROR ADDED 0%

0.15091E-04	0.74191E-06	0.29935E-06	0.63129E-06	0.44247E-06
0.15076E-04	0.50355E-06	0.60773E-06	0.39292E-06	0.75086E-06
0.15065E-04	0.32905E-06	0.83349E-06	0.32905E-06	0.83349E-06
0.15069E-04	0.39292E-06	0.75086E-06	0.50355E-06	0.60773E-06
0.15084E-04	0.63129E-06	0.44247E-06	0.74191E-06	0.29935E-06
0.15095E-04	0.80579E-06	0.21672E-06	0.80579E-06	0.21672E-06

103

COEFFICIENTS A, READ ROW WISE

```
0.33237E-07  0.105855E-08  0.105855E-08  0.105855E-08  0.105855E-08
0.33237E-07  0.105855E-08  0.105855E-08  0.105855E-08  0.105855E-08
0.33237E-07  0.105855E-08  0.105855E-08  0.105855E-08  0.105855E-08
0.33237E-07  0.105855E-08  0.105855E-08  0.105855E-08  0.105855E-08
0.33237E-07  0.105855E-08  0.105855E-08  0.105855E-08  0.105855E-08
0.33237E-07  0.105855E-08  0.105855E-08  0.105855E-08  0.105855E-08
```

COEFFICIENTS B, READ ROW WISE

```
-0.96676E-08  0.225111E-07  0.225111E-07  0.225111E-07  0.225111E-07
-0.96676E-08  0.225111E-07  0.225111E-07  0.225111E-07  0.225111E-07
-0.96676E-08  0.225111E-07  0.225111E-07  0.225111E-07  0.225111E-07
-0.96676E-08  0.225111E-07  0.225111E-07  0.225111E-07  0.225111E-07
-0.96676E-08  0.225111E-07  0.225111E-07  0.225111E-07  0.225111E-07
-0.96676E-08  0.225111E-07  0.225111E-07  0.225111E-07  0.225111E-07
```

COEFFICIENTS C, READ ROW WISE

```
0.0         0.371156E-07  -0.371156E-07  0.371156E-07  -0.371156E-07
0.0         0.371156E-07  -0.371156E-07  0.371156E-07  -0.371156E-07
0.0         0.371156E-07  -0.371156E-07  0.371156E-07  -0.371156E-07
0.0         0.371156E-07  -0.371156E-07  0.371156E-07  -0.371156E-07
0.0         0.371156E-07  -0.371156E-07  0.371156E-07  -0.371156E-07
0.0         0.371156E-07  -0.371156E-07  0.371156E-07  -0.371156E-07
```

EXPANSION WITH 11 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

CONSTANTS
TANG.   0.45455E 03
LONG.   0.28944E 01
SHEAR   0.56925E 00

	COS 1(THETA)	SIN 1(THETA)	COS 2(THETA)	SIN 2(THETA)	COS 3(THETA)	SIN 3(THETA)
TANG.	-0.57441E-03	0.32390E-04	-0.56746E-04	-0.58088E-04	0.54121E-04	-0.11337E-04
LONG.	-0.11386E 01	-0.11385E 01	-0.43307E-04	-0.76463E-04	-0.74386E-05	-0.55022E-04
SHEAR	-0.53861E 01	-0.53866E 01	-0.52491E-05	0.28910E-05	-0.14306E-05	-0.13928E-05

	COS 4(THETA)	SIN 4(THETA)	COS 5(THETA)	SIN 5(THETA)
TANG.	0.76199E-04	0.11885E-04	0.38986E-04	-0.78963E-05
LONG.	0.41156E-04	-0.55075E-04	-0.13349E-04	0.45193E-04
SHEAR	0.10598E-05	-0.10318E-05	0.22680E-06	-0.69870E-06

```
THETA =    0 DEGREES       POINT NO.   1
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.17552E 01        0.59553E 01
COMPUTED        0.45455E 03        0.17558E 01        0.59553E 01


THETA =   10 DEGREES       POINT NO.  11
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.19702E 01        0.49382E 01
COMPUTED        0.45455E 03        0.19707E 01        0.49382E 01


THETA =   20 DEGREES       POINT NO.  21
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.22133E 01        0.37884E 01
COMPUTED        0.45455E 03        0.22137E 01        0.37884E 01


THETA =   30 DEGREES       POINT NO.  31
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.24770E 01        0.25407E 01
COMPUTED        0.45455E 03        0.24774E 01        0.25407E 01


THETA =   40 DEGREES       POINT NO.  41
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.27534E 01        0.12331E 01
COMPUTED        0.45455E 03       .0.27538E 01        0.12331E 01


THETA =   50 DEGREES       POINT NO.  51
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.30341E 01       -0.94609E-01
COMPUTED        0.45455E 03        0.30345E 01       -0.94604E-01


THETA =   60 DEGREES       POINT NO.  61
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.33104E 01       -0.14022E 01
COMPUTED        0.45455E 03        0.33110E 01       -0.14022E 01


THETA =   70 DEGREES       POINT NO.  71
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.35742E 01       -0.26498E 01
COMPUTED        0.45455E 03        0.35748E 01       -0.26498E 01


THETA =   80 DEGREES       POINT NO.  81
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.38172E 01       -0.37997E 01
COMPUTED        0.45455E 03        0.38180E 01       -0.37997E 01


THETA =   90 DEGREES       POINT NO.  91
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.40322E 01       -0.48168E 01
COMPUTED        0.45455E 03        0.40331E 01       -0.48168E 01


THETA =  100 DEGREES       POINT NO. 101
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.42126E 01       -0.56702E 01
COMPUTED        0.45455E 03        0.42135E 01       -0.56702E 01


THETA =  110 DEGREES       POINT NO. 111
STRESSES          TANG.              LONG.              SHEAR
ACTUAL          0.45455E 03        0.43530E 01       -0.63341E 01
COMPUTED        0.45455E 03        0.43537E 01       -0.63341E 01
```

APPENDIX C

DIGITAL COMPUTER PROGRAM FOR SECTION 3 AND NUMERICAL RESULTS

Subroutine MACUTO presented in this Appendix provides a method for applying the theory developed in Section 3. Data for simulated situations can be obtained from subroutine CANTIL presented in Appendix A.

MACUTO has been programmed following closely the development of the method. Self explanatory comment statements are included, which detail the type of data to be used and the procedural sequence of the method. Print-outs present the data processed and the computed loading.

Use of the subroutines is made by a brief main program called TIBISAY. This program merely dimensions the subroutines, accepts and prepares the input data, and turns control over to subroutine MACUTO. The card arrangement of the source deck is similar to that shown in Fig. B.1.

Some sample results of the application made of the programs as specified in Section 3 are presented following the card listings of the programs.

```
//TIBISAY  JOB  ...,'TAMIPDA, JESUS A.',MSCLEVEL=1
//TAB    EXEC  FORTCLG                                   00000010
//FORT   EXEC  PGM=IEYFORT

      DIMENSION AFL(3),AXM1(3),AF(3),AXM(3),F(3),XM(3),FWGHT(3),   CANTIL
     1XLI(5),XL2(3),FR(3),FT(3),R(3),ALLI(3,360,5),                CANTIL
     2SHIZT(3),SHZZ(3),SAZZ(3),SHEZE(3),SHEZT(3),SPRR(3),SPTT(3)   CANTIL
      DIMENSION F(3,3)                                             TRANSF
      DIMENSION FORCE(3),XMOM(3),THETA(3),ST(3),SL(3),SH(3),Y(3,3) MACUTO
      DIMENSION A1(3),A2(3),A3(3),A4(3),F3(3),F5(3),F6(3),         SCRATCH
     1XM3(3),XM4(3),XM5(3),XM6(3),B1(3),B2(3),B3(3),B4(3),B5(3),B6(3) SCRATCH

C  SPECIFY POISSON'S RATIO V, EXTERNAL AND INTERNAL PIPE DIAMETERS DO
C  AND DI, ANGULAR POSITION THETA OF THE POINTS AND STRESS COMPONENTS:
C  TANGENTIAL ST, LONGITUDINAL SL AND SHEAR SH OF THE THREE POINTS 1,
C  2, AND 3.
C
C  IF THE MATHEMATICAL MODEL OF A PIPE IS USED, OUTPUT ARGUMENTS OF
C  SUBROUTINE CANTIL, XNU AND ALLI CAN BE USED FOR THIS.
C
      CALL    CANTIL(FD,RI,XE,G,XNU,SPECW,D,XL1,NPOINT,APFA,ALLI)
      V = XNU
      DO = RO + RC
      DI = RI + RC
      THETA(1) = 120.0
      THETA(2) = 120.0
      THETA(3) = 240.0
      ST(1) = ALLI(1,1,1)
      ST(2) = ALLI(1,121,1)
      ST(3) = ALLI(1,241,1)
      SL(1) = ALLI(2,1,1)
      SL(2) = ALLI(2,121,1)
      SL(3) = ALLI(2,241,1)
      SH(1) = ALLI(3,1,1)
      SH(2) = ALLI(3,121,1)
      SH(3) = ALLI(3,241,1)
C
C  PREPARE STRESSES FOR INPUT TO MACUTO.
C
      DO 1 I = 1,3
      Y(1,I) = ST(I)
      Y(2,I) = SL(I)
    1 Y(3,I) = SH(I)
```

```
C
C     EVALUATE THE LOADING AT THE CROSS SECTION OF PIPE.
C
      CALL MACUTC(DC,DI,V,Y,THETA,P,FORCF,XMOM)
C
C
      END
```

```
      SUBROUTINE MACUTO(DO, DI, V, ALL, THETA, P, F, YM)                   MACUTO001
C                                                                          MACUTO002
C     TO FIND THE LOADING ACTING THROUGH THE CROSS SECTION OF A PIPE FROM  MACUTO003
C     THE STRESS COMPONENTS AT THREE POINTS OF THE EXTERNAL CIRCUMFERENCE  MACUTO004
C     OF THE CROSS SECTION.                                                MACUTO005
C                                                                          MACUTO006
C                                                                          MACUTO007
C     DO AND DI ARE EXTERNAL AND INTERNAL DIAMETERS OF THE PIPE RESPECTI-  MACUTO008
C     VELY.                                                                MACUTO009
C     V IS POISSON'S RATIO.                                                MACUTO010
C     ALL IS A 3X3 ARRAY CONTAINING THE STRESS COMPONENTS FOR THE THREE    MACUTO011
C     POINTS.                                                              MACUTO012
C     THETA IS AN ARRAY CONTAINING THE ANGULAR POSITIONS OF THE POINTS.    MACUTO013
C     P IS THE INFERRED INTERNAL PRESSURE OF THE PIPE.                     MACUTO014
C     F IS THE INFERRED FORCE.                                             MACUTO015
C     M IS THE INFERRED MOMENT.                                            MACUTO016
C                                                                          MACUTO017
C                                                                          MACUTO018
      DIMENSION F(3), XM(3), ALL(3,3), THETA(3)                           MACUTO019
      ABCF(A1,A2,A3,B1,B2,B3) = A1*B1+A2*B2+A3*B3                         MACUTO020
      WRITE(6, 500)                                                        MACUTO021
  500 FORMAT(1H1, 7(/), 15X, 'INFERRED LOADING' // )                      MACUTO022
      RO2 = DO*DO/4.0                                                      MACUTO023
      RI2 = DI*DI/4.0                                                      MACUTO024
      PI = 3.1415926                                                       MACUTO025
      AREA = PI*(RO2 - RI2)                                                MACUTO026
      ERTIA = AREA*(RO2 + RI2)/4.0                                         MACUTO027
      THETA2 = PI/18.0                                                     MACUTO028
      ENE = V + 1.0                                                        MACUTO029
      Q = ((2.0*ENE - 2.0)*RO2 + 2.0*ENE*RI2)/(4.0*ERTIA*(1.0 + V))       MACUTO030
C                                                                          MACUTO031
C     IDENTIFY THE STRESS COMPONENTS, TANGENTIAL SPTT, LONGITUDINAL S      MACUTO032
C     AND SHEAR T FOR POINTS 1, 2, AND 3 FROM ARRAY ALL.                   MACUTO033
C                                                                          MACUTO034
C                                                                          MACUTO035
      SPTT1 = ALL(1, 1)                                                    MACUTO036
      S1   = ALL(2, 1)                                                     MACUTO037
      T1   = ALL(3, 1)                                                     MACUTO038
      SPTT2 = ALL(1, 2)                                                    MACUTO039
      S2   = ALL(2, 2)                                                     MACUTO040
      T2   = ALL(3, 2)                                                     MACUTO041
      SPTT3 = ALL(1, 3)                                                    MACUTO042
      S3   = ALL(2, 3)                                                     MACUTO043
      T3   = ALL(3, 3)                                                     MACUTO044
C                                                                          MACUTO045
C                                                                          MACUTO046
                                                                           MACUTO047
                                                                           MACUTO048
```

110

MACUTC040
MACUTC051
MACUTC052
MACUTC053
MACUTC054
MACUTC056
MACUTC057
MACUTC058
MACUTC059
MACUTC060
MACUTC061
MACUTC062
MACUTC063
MACUTC064
MACUTC065
MACUTC067
MACUTC068
MACUTC069
MACUTC071
MACUTC072
MACUTC073
MACUTC074
MACUTC075
MACUTC076
MACUTC077
MACUTC078
MACUTC079
MACUTC080
MACUTC081
MACUTC082
MACUTC083
MACUTC085
MACUTC086
MACUTC087
MACUTC088
MACUTC089
MACUTC090
MACUTC091
MACUTC092
MACUTC093
MACUTC094
MACUTC095
MACUTC096

```
C     CONVERT ANGULAR DEGREES TO RADIANS AND FIND DIFFERENCES BETWEEN
C     ANGLES.  FIND DIFFERENCES BETWEEN STRESS COMPONENTS.

      GG1=THETA(1)*THETA2
      GG2=THETA(2)*THETA2
      GG3=THETA(3)*THETA2
      GG12=(THETA(1)-THETA(2))*THETA2
      GG23=(THETA(2)-THETA(3))*THETA2
      GG31=(THETA(3)-THETA(1))*THETA2
      SINF12=SIN(GG12)
      SINF23=SIN(GG23)
      SINF31=SIN(GG31)
      COSF1=COS(GG1)
      COSF2=COS(GG2)
      COSF3=COS(GG3)
      S21=S2-S1
      S32=S3-S2
      S13=S1-S3
      T21=T2-T1
      T32=T3-T2
      T13=T1-T3

C     OBTAIN DENOMINATOR AND NUMERATOR OF THE FORCE AND MOMENT COMPONENTS.
C     PERFORM THE CORRESPONDING DIVISIONS TO SOLVE FOR THE COMPONENTS.

      DENUM=ARCF(1.0,1.0,1.0,SINF12,SINF23,SINF31)
      XMXNUM=ARCF(COSF1,COSF2,COSF3,S32,S13,S21)
      XMYNUM=ARCF(COSF1,COSF2,COSF3,T32,T13,T21)
      XMZNUM=ARCF(SINF12,SINF23,SINF31,T32,T13,T21)
      FXNUM=ABCF(T1,T2,T3,SINF23,SINF31,SINF12)
      FYNUM=ABCF(S1,S2,S3,SINF23,SINF31,SINF12)
      FZNUM=ABCF(1.0,1.0,1.0,SINF23,SINF31,SINF12)
      XXM(1)=XMXNUM/DENUM/CENCM**ERTIA
      XXM(2)=XMYNUM/DENUM/CENCM**ERTIA
      XXM(3)=XMZNUM/DENUM/CENCM**ERTIA*2.0
      F(1)=-FXNUM/DENUM/D
      F(2)=-FYNUM/DENUM/D
      F(3)=FZNUM/DENUM*AREA

C     SOLVE FOR THE INTERNAL PRESSURE.
```

111

```
                                                                    MACUT097
                                                                    MACUT098
                                                                    MACUT099
                                                                    MACUT100
                                                                    MACUT101
                                                                    MACUT102
                                                                    MACUT103
                                                                    MACUT104
                                                                    MACUT105
                                                                    MACUT106
                                                                    MACUT107
                                                                    MACUT108
                                                                    MACUT109
                                                                    MACUT110
                                                                    MACUT111
                                                                    MACUT112
                                                                    MACUT113
                                                                    MACUT114
                                                                    MACUT115
                                                                    MACUT116
                                                                    MACUT117
                                                                    MACUT118

      P = ( SPTT1 + SPTT2 + SPTT3 )*( RO2/RI2 - 1.0 )/5.0

C
C     PREPARE PRINT-OUTS OF THE INFORMATION PROCESSED AND THE INFERRED
C     LOADING.
C
      WRITE(6, 2)   THETA(1), (ALL(I,1), I = 1, 3),
     1              THETA(2), (ALL(I,2), I = 1, 3),
     2              THETA(3), (ALL(I,3), I = 1, 3)
    2 FORMAT( //, 15X, 'STRESSES', 28X, 'TANG.', 17X, 'LONG.', 17X,
     1  'SHEAR', 15X, 'THETA =', F7.2, ' DEGREES', 3E22.5 /), 17X, ) )
      WRITE(6, 3)  P, F, XM
    3 FORMAT( //, 15X, 'INFERRED PRESSURE', 3E20.5, ' PSI' /
     1          15X, 'INFERRED FORCE', 3E20.5, ' LBS' /
     2          15X, 'INFERRED MOMENT', 3E20.5, ' LB-IN' )
C
C     RETURN
      END
```

112

INTERNAL LOADING.

STRESSES

THETA		TANG.	LONG.	SHEAR
THETA = 0.0 DEGREES		0.45455E 03	-0.89505E 02	0.59553E 01
THETA = 120.00 DEGREES		0.45455E 03	0.16090E 02	-0.20473E 02
THETA = 241.00 DEGREES		0.45455E 03	0.74187E 02	0.16226E 02

INFERRED PRESSURE   0.10000E 03 PSI
INFERRED FORCE   0.38330E 03   0.99999E 02 LBS
INFERRED MOMENT   -0.20000E 04   0.75000E 04   0.10000E 03 LB-IN

RADIAL DISTANCE OF POINTS = 6.00000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE = 100.00 PSI
APPLIED FORCE = 100.00   100.00   100.00 LB
APPLIED MOMENT = 100.00   100.00   100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION   30.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE = 100.00 PSI
APPLIED FORCE = 393.39   100.00   100.00 LB
APPLIED MOMENT = -2000.00   7500.00   100.00 LB-IN

The stresses used as input for this inference were taken from this data which is similar to that shown in pg. . The inferred loading is in agreement with the actual one acting on the cross section.

Subroutine DSIMQ of the Computer Facility Center of the Naval Postgraduate School, to solve linear simultaneous equations.

```
C     SUBROUTINE DSIMQ                                              DSIMQ0002
C                                                                   DSIMQ0003
C     THIS WAS SLIGHTLY MODIFIED TO BE USED IN SINGLE PRECISION.    DSIMQ0004
C                                                                   DSIMQ0005
C     PURPOSE                                                       DSIMQ0006
C        OBTAIN SOLUTION OF A SET OF SIMULTANEOUS LINEAR EQUATIONS, DSIMQ0007
C        AX=B                                                       DSIMQ0008
C                                                                   DSIMQ0009
C     USAGE                                                         DSIMQ0010
C        CALL DSIMQ(A,B,N,KS)                                       DSIMQ0011
C                                                                   DSIMQ0012
C     DESCRIPTION OF PARAMETERS                                     DSIMQ0013
C        A - MATRIX OF COEFFICIENTS STORED COLUMNWISE. THESE ARE    DSIMQ0014
C            AND MUST BE REAL*8. THE SIZE OF MATRIX A IS            DSIMQ0015
C            DESTROYED IN THE COMPUTATION.                          DSIMQ0016
C                                                                   DSIMQ0017
C        B - VECTOR OF ORIGINAL CONSTANTS (LENGTH N). THESE ARE     DSIMQ0018
C            REPLACED BY FINAL SOLUTION VALUES, VECTOR X.           DSIMQ0019
C        N - NUMBER OF EQUATIONS AND VARIABLES                      DSIMQ0020
C        KS - OUTPUT DIGIT                                          DSIMQ0021
C             0 FOR A NORMAL SOLUTION                               DSIMQ0022
C             1 FOR A SINGULAR SET OF EQUATIONS                     DSIMQ0023
C                                                                   DSIMQ0024
C     REMARKS                                                       DSIMQ0025
C        MATRIX A MUST BE GENERAL.                                  DSIMQ0026
C        IF MATRIX A IS SINGULAR, SOLUTION VALUES ARE MEANINGLESS.  DSIMQ0027
C        AN ALTERNATIVE SOLUTION MAY BE OBTAINED BY USING MATRIX    DSIMQ0028
C        INVERSION (MINV) AND MATRIX PRODUCT (GMPRD).               DSIMQ0029
C                                                                   DSIMQ0030
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED ... NONE        DSIMQ0031
C     METHOD                                                        DSIMQ0032
C        METHOD OF SOLUTION IS BY ELIMINATION USING LARGEST PIVOTAL DSIMQ0033
C        DIVISOR. EACH STAGE OF ELIMINATION CONSISTS OF INTERCHANGINGDSIMQ0034
C        ROWS WHEN NECESSARY TO AVOID DIVISION BY ZERO OR SMALL     DSIMQ0035
C        ELEMENTS. THE FORWARD SOLUTION TO OBTAIN VARIABLE N IS DONE INDSIMQ0036
C        N STAGES. THE BACK SOLUTION FOR THE OTHER VARIABLES IS     DSIMQ0037
C        CALCULATED BY SUCCESSIVE SUBSTITUTIONS. FINAL SOLUTION IS  DSIMQ0038
C        VALUES ARE DEVELOPED IN VECTOR B, WITH VARIABLE 1 IN B(1), DSIMQ0039
C        VARIABLE 2 IN B(2),.... VARIABLE N IN B(N).•               DSIMQ0040
C        IF NO PIVOT CAN BE FOUND EXCEEDING A TOLERANCE OF 0.0, THIS DSIMQ0041
C        THE MATRIX IS CONSIDERED SINGULAR AND KS IS SET TO 1. THIS DSIMQ0042
C        TOLERANCE CAN BE MODIFIED BY REPLACING THE FIRST STATEMENT.DSIMQ0043
C                                                                   DSIMQ0044
```

```
      SUBROUTINE DSIMQ(A,B,N,KS)                        DSIMQ0048
      REAL*8 A,B,BIGA,TOL,SAVE,DABS                     DSIMQ0049
      DIMENSION A(1),B(1)                               DSIMQ0050
C                                                       DSIMQ0051
C        FORWARD SOLUTION                               DSIMQ0052
C                                                       DSIMQ0053
      TOL=0.000                                         DSIMQ0054
      TOL=0.0                                           DSIMQ0055
      KS=0                                              DSIMQ0056
      JJ=-N                                             DSIMQ0057
      DO 65  J=1,N                                      DSIMQ0058
      JY=J+1                                            DSIMQ0059
      JJ=JJ+N+1                                         DSIMQ0060
      BIGA=0.000                                        DSIMQ0061
      IT=JJ-J                                           DSIMQ0062
      DO 30 I=J,N                                       DSIMQ0063
C                                                       DSIMQ0064
C        SEARCH FOR MAXIMUM COEFFICIENT IN COLUMN       DSIMQ0065
C                                                       DSIMQ0066
      IJ=IT+I                                           DSIMQ0067
      IF(DABS(BIGA)-DABS(A(IJ))) 20,30,30               DSIMQ0067
      IF( ABS(BIGA)- ABS(A(IJ))) 20,30,30               DSIMQ0068
   20 BIGA=A(IJ)                                        DSIMQ0069
      IMAX=I                                            DSIMQ0070
   30 CONTINUE                                          DSIMQ0071
C                                                       DSIMQ0072
C        TEST FOR PIVOT LESS THAN TOLERANCE (SINGULAR MATRIX)  DSIMQ0073
C                                                       DSIMQ0074
      IF( DABS(BIGA)-TOL) 35,35,40                      DSIMQ0074
      IF( ABS(BIGA)-TOL) 35,35,40                       DSIMQ0075
   35 KS=1                                              DSIMQ0076
      RETURN                                            DSIMQ0077
C                                                       DSIMQ0078
C        INTERCHANGE ROWS IF NECESSARY                  DSIMQ0079
C                                                       DSIMQ0080
   40 I1=J+N*(J-2)                                      DSIMQ0081
      IT=IMAX-J                                         DSIMQ0082
      DO 50 K=J,N                                       DSIMQ0083
      I1=I1+N                                           DSIMQ0084
      I2=I1+IT                                          DSIMQ0085
      SAVE=A(I1)                                        DSIMQ0086
      A(I1)=A(I2)
```

```
C     DIVIDE EQUATION BY LEADING COEFFICIENT                          DSIMQ088
C                                                                     DSIMQ089
50    A(IJ)=A(IJ)/BIGA                                                DSIMQ090
      SAVE=B(IMAX)                                                    DSIMQ091
      B(IMAX)=B(J)                                                    DSIMQ092
      B(J)=SAVE/BIGA                                                  DSIMQ093
C                                                                     DSIMQ094
C     ELIMINATE NEXT VARIABLE                                         DSIMQ095
C                                                                     DSIMQ096
55    IF(J-N) 55,70,55                                                DSIMQ097
      IQS=N*(J-1)                                                     DSIMQ098
      DO 65 IX=JY,N                                                   DSIMQ099
      IXJ=IQS+IX                                                      DSIMQ100
      IT=J-IX                                                         DSIMQ101
      DO 60 JX=JY,N                                                   DSIMQ102
      IXJX=N*(JX-1)+IX                                                DSIMQ103
      JJX=IXJX+IT                                                     DSIMQ104
60    A(IXJX)=A(IXJX)-(A(IXJ)*A(JJX))                                 DSIMQ105
65    B(IX)=B(IX)-(B(J)*A(IXJ))                                       DSIMQ106
C                                                                     DSIMQ107
C     BACK SOLUTION                                                   DSIMQ108
C                                                                     DSIMQ109
70    NY=N-1                                                          DSIMQ110
      IT=N*N                                                          DSIMQ111
      DO 80 J=1,NY                                                    DSIMQ112
      IA=IT-J                                                         DSIMQ113
      IB=N-J                                                          DSIMQ114
      IC=N                                                            DSIMQ115
      DO 80 K=1,J                                                     DSIMQ116
      B(IB)=B(IB)-A(IA)*B(IC)                                         DSIMQ117
      IA=IA-N                                                         DSIMQ118
80    IC=IC-1                                                         DSIMQ119
      RETURN.                                                         DSIMQ120
      END                                                             DSIMQ121
                                                                      DSIMQ122
```

116

APPENDIX E

Effects of Changing the Number of Fourier Coefficients and the Amount and Quality of the Data in the Application of the Theory Developed in Section 2.

The theory developed in Section 2 of this thesis estimates Fourier coefficients of the distributions of axial, tangential, and shear stresses assuming that enough data has been obtained by placing a sufficient number of strain gage elements around the external surface of a cross section of pipe. The correctness of the estimated coefficients depends on their number and on the amount and quality of the data. Depending on the relative orientation of the gage elements, they can pick information useful for determining the coefficients of all the distributions, or, if they are arranged in certain disadvantageous ways, they may be able to provide information for none, or only some of the coefficients.

The requirement of inferring a given number N of Fourier coefficients, demands having, at a minimum, a corresponding number $M = M(N)$ of valid data items. If more data are available, there is a redundance of data which permits more accurate determination of the N coefficients.

Specific rules for the necessary number and disposition of gage elements to obtain a specified number of correct coefficients are not available, but they probably could be worked out. Some idea of the gage elements requirements can be obtained by testing actual cases and comparing results with correct ones obtained from other methods. The digital computer programs included in this thesis can be used as they are to perform such tests. The procedure to follow is to simply specify in subroutine ZULIA the number of gage elements, their angular positions and angular orientations around the cross section, and the number of Fourier coefficients to be computed. The print-out of this program presents the

117

distributions obtained in this way, shown adjacent to the theoretically correct ones, so that comparisons can be readily done.

A preliminary survey of gage elements arrangements was made using that procedure, applied to data with no added random errors. Results obtained are presented following these pages. Many of these results might have been anticipated from theoretical considerations. The following nomenclature is used when applicable:

(a) No. of coefficients

3 to 11: the results presented were obtained using from three to eleven Fourier coefficients per series. These results apply to that number of coefficients.

7: results apply only to seven coefficients.

(b) Results

good: indicates that the coefficients obtained describe correctly the tangential, axial and shear stress distributions.

bad: The computed coefficients do not describe either of the distributions.

only shear good: good coefficients were obtained only for the shear stress distribution.

Inasmuch as the data were without added errors, the recovery should be and actually was excellent or no good at all; accordingly, there is nothing subjective in the judgment "good" or "bad".
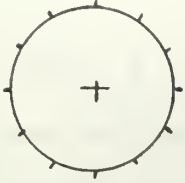
Gage elements located at 12 points equally spaced 30° around the external circumference of the cross section.
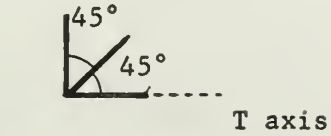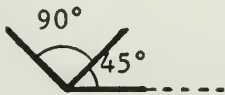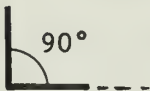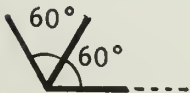
| gage elements arrangement at each point	No. of Fourier coefficients per series	results
45° 45° T axis	3 to 11	good
90° 45°	3 to 11	good
90° 45°	3 to 11	only shear good
45°	3 to 11	bad
90°	3 to 11	bad
60° 60°	3 to 11	good
60° 60°	3 to 11	only shear good
60°	3 to 11	bad

II)

Gage elements located at 8 points equally spaced 45° around the external circumference of the cross section.

gage elements arrangement at each point	No. of Fourier coefficients per series	results
	3 to 7	good
same	9 and 11	bad
	3 to 7	good
same	9 and 11	bad
	3 to 7	only shear good
same	9 and 11	bad
	3 to 11	bad
	3 to 11	bad
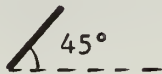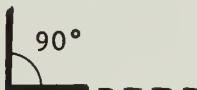
III)

One gage element every 10° around the external circumference of the cross section, totaling 36 elements. The first element at 0° from the tangential direction, and every consecutive one, incrementing this angle by 10°.

from 3 to 11 coefficients: bad results

IV)

One gage element every 10° around the external circumference of the cross section, totaling 36 elements. The first element at 0° from the tangential direction, and every consecutive one, incrementing this angle by 50°.

from 3 to 9 coefficients: good results

11 coefficients: bad results

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13. ABSTRACT

This thesis presents a method for estimating the distribution of stress components around the outer circumference of a cross section of a pipe, from the readings of strain gage elements arbitrarily positioned and oriented around this circumference. A least-squares procedure is used to obtain best estimates of the coefficients of Fourier expansions describing such distributions. A digital computer program was developed for applying the method. Data for testing the method and program were generated by a computer program using the best available theory of stress analysis in pipes. Methods for adding random errors to the data were adapted and used for closer simulation of actual situations.

A second problem treated in this thesis is that of inferring the loading acting through the cross section of a straight pipe of concentric bore from known stresses at points on the external surface of the cross section which is presumed to be distant from stress condentrations. It is shown that this inference can be made from stresses at only three points of the cross section. A digital computer program was developed to do this.

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124

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